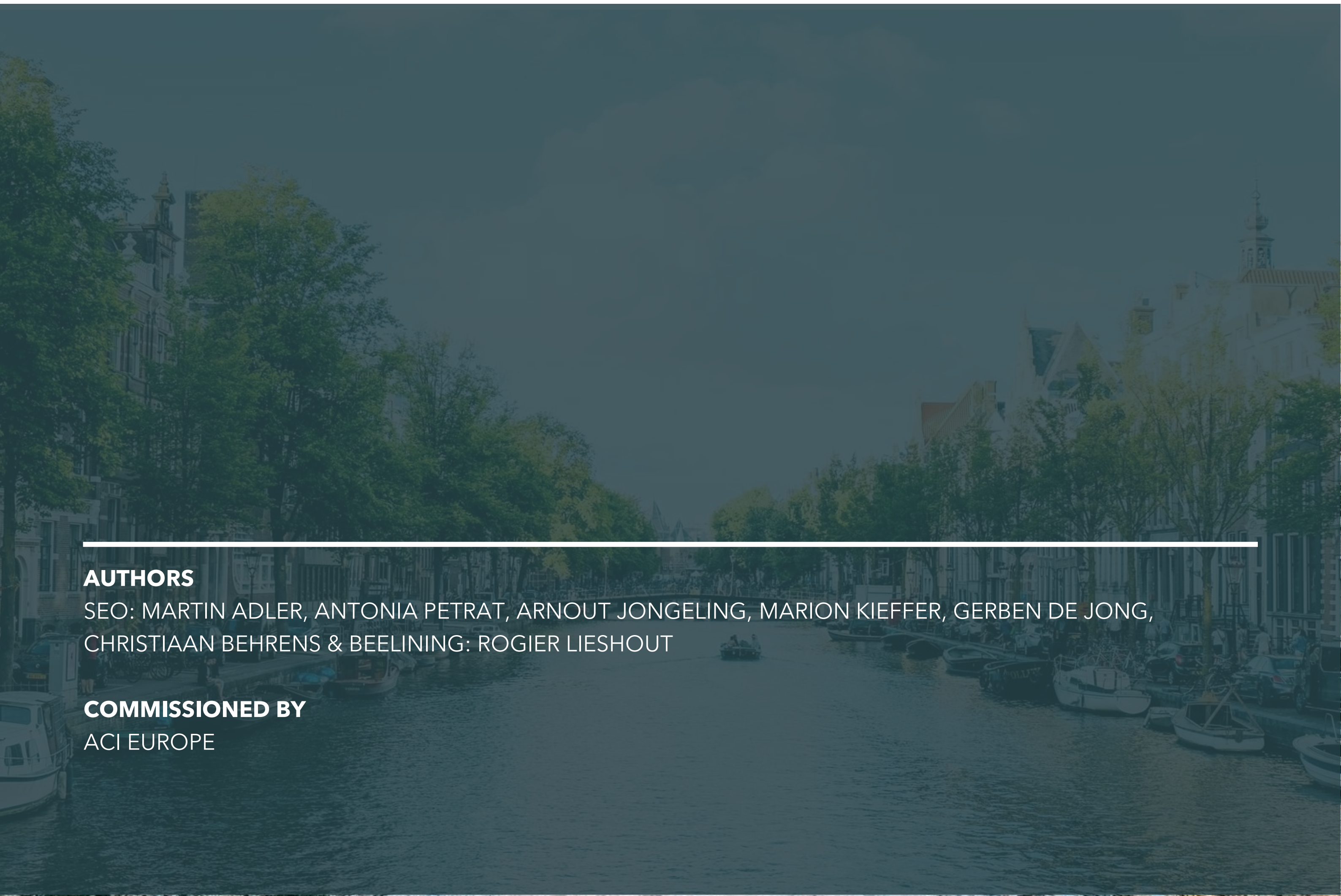
THE ECONOMIC AND SOCIAL IMPACT OF EUROPEAN AIRPORTS AND AIR CONNECTIVITY

FULL REPORT



AUTHORS
SEO: MARTIN ADLER, ANTONIA PETRAT, ARNOUT JONGELING, MARION KIEFFER, GERBEN DE JONG, CHRISTIAAN BEHRENS & BEELINING: ROGIER LIESHOUT

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Executive summary

The European aviation sector facilitates increased air connectivity with a positive impact on the economy via GDP and employment. Additionally, increased air connectivity produces positive and negative externalities such as wider economic (catalytic) benefits and greenhouse gas emissions. Air connectivity also contributes to broader social outcomes such as well-being, education, and more intense cooperation between countries.

Background & methodology

ACI EUROPE commissioned SEO Amsterdam Economics to conduct a study on the economic and social impact of European airports and air connectivity. Our study includes the analysis of traditional economic measures, such as Gross Domestic Product (GDP), less traditional (economic) measures, such as well-being, and externalities, such as airports' contribution to global CO_2 emissions.

This study examines the activities and impacts of European airports by looking at ACI EUROPE's member airports. The more than 500 ACI EUROPE's member airports handle about 90% of all commercial air traffic in Europe. To examine the activities and impacts, this study collects data from the members via online surveys and matches this to air connectivity measured via SEO's NetScan connectivity model and publicly available socio-economic data for European regions. The obtained information has been analysed using a variety of tools including descriptive analysis, input-output analysis and advanced econometric (regression) modelling. Figure S.1 provides a summary of our main results.

Main outcome 1: gross economic impact

From 2004-2019, direct flights, passenger numbers, cargo, and Gross Domestic Product (GDP) increased all over Europe. Passenger growth (63%) outpaced GDP growth (45%), airport connectivity growth (24%), and cargo growth (25%).

European airports directly contribute €121 billion in GDP and 1.8 in million jobs. Indirectly, they support €89 billion in GDP and 1.1 in million jobs through the purchase of goods and services. Additionally, induced effects from wage expenditures contribute €121 billion in GDP and 1.7 in million jobs. Tourism that is enabled by air transport adds approximately €174 billion in GDP whilst supporting around 3.5 million jobs in Europe.

The total gross economic impact, measured as the sum of direct, indirect, induced and tourism impact, therefore amounts to approximately €505 billion in GDP and 8.1 million jobs in 2019. This equals around 2.8% of the total economy in the European Economic Area and 3.6% of the total workforce.

Main outcome 2: net economic impact

The net economic impact measures the change of regional productivity resulting from air connectivity considering wider regional economic factors, such as price and supply side developments. To isolate and identify this impact of aviation on regional economies, the study applies spatial econometric models with longitudinal data over the period 2004-2019. These models explain changes in regional economic activity over time resulting from the increased supply of air connectivity. Our findings show that connectivity has a positive effect on GDP. A 10% increase in direct flights leads to a 0.5% increase in GDP. The 10% increase of connectivity is chosen as an illustration of the elasticity of the marginal effect. During this 15 year time period under observation, connectivity of airports increased on average by 24%. Similar to the effect on GDP, there is a positive effect on employment, with a 10% increase in direct flights resulting in a 1.6% increase in employment. Broadly speaking, the net economic impact measures changes in GDP and employment from aviation activity in the regional context while the gross economic impact sums up all economic activity linked to airports. Thereby, the net impact extends beyond the gross impact by including all positive and negative effects to the wider regional economy from catalytic benefits such as trade and innovation but also potentially negative effects from labor market and price realignments.

Main outcome 3: social impact

Airports have a broader societal impact that is arguably not fully captured by traditional economic indicators such as GDP and employment alone. In the public and policy debate, airport activity is regularly linked to social developments. The exploration of the relationships between connectivity and various socio-economic indicators reveals that connectivity is a powerful driver of socioeconomic progress, exerting a positive influence on various indicators. This study examines the relationship over time between air connectivity and:

- No poverty and zero hunger (Sustainable Development Goals 1 and 2)
- Good health and well-being (SDG 3)
- Quality of education (SDG 4)
- Gender equality and reduced inequalities (SDG 5 and 10)
- Industry, innovation and infrastructure (SDG 9)
- Peace, justice and strong institutions (SDG 16)
- Partnerships for UN SDG Goals (SDG 17)

The empirical findings suggest that connectivity acts as a catalyst for positive socioeconomic progress, driving development across multiple areas. For all indicators listed above, connectivity has indirect effects mediated through GDP and employment. Higher levels of connectivity stimulate economic growth, leading to higher GDP levels. This in turn contributes, amongst others, to improved research funding, healthcare infrastructure, and overall quality of life.

Main outcome 4: global and local externalities

Aviation activity yields external costs, including local pollution and contribution to global warming. These negative externalities of aviation specifically relate to SDG's 11 (Sustainable cities and communities), 13 (Climate action) and 15 (Life on land). Balancing the economic benefits with environmental sustainability is crucial for the sector's long-term development. The aviation sector is currently engaged with decarbonization efforts through Destination 2050 and ACI Airport Carbon Accreditation.

This study estimates these environmental impacts for 2019 in terms of climate change, air pollution and noise for each flight and aggregate the effects at the airport level. Flights departing from European origins emitted an estimated 211 Mt of CO_2. The non-CO_2 emissions of European aviation is estimated at 422 Mt CO_2 equivalents. These emissions differ significantly between airports depending on flight activity and average flight distance (routes served). From a global perspective, flights departing from European origins were responsible for about 21% of aviation-related pollutant emissions in 2019, this corresponds to the share of European aviation in global flight movements (about 22% in the same year). Noise impacts around airports depend on multiple airport-specific factors, such as traffic volume, fleet mix, population density, air traffic management, runway layout, airport opening hours etc. A detailed noise assessment for each airport is beyond the scope of the current study. Looking at available key figures regarding noise exposure data for European airport from 2017, this study could not establish a clear relationship between noise exposure and traffic volume. This suggest that other factors, such as the use and orientation of runways vis-à-vis population centers, are more relevant for explaining differences in noise exposure.

Main outcome 5: Combining results into a footprint

The study provides a quantification of the combined aggregated effect, which could be labelled as a footprint. Since not all effects are monetized, such as the environmental impacts, the footprint does not give a complete picture. Under the assumption that the average estimated elasticities in the net economic impact modelling are constant over the entire range of connectivity values, the impact of 100% change in connectivity equals 100 times the elasticity, hence 5%. In other words, 5% of total European GDP is associated with aviation, approximately €850 billion. In terms of employment this relates to 6% of all employment, or about 14 million jobs.

Research challenges

Our report documents the complex but clear relationship between air connectivity on the one hand and economic and social impact on the other hand. This study presents figures for the European airports, but also shows the heterogenous nature of the outcomes. Southern and Eastern European airports, for example, grew faster in connectivity and are catching up to Northern and Western European airports. The report details further limitations, such as external validity regarding other airports or future connectivity developments and performs substantial robustness checks.

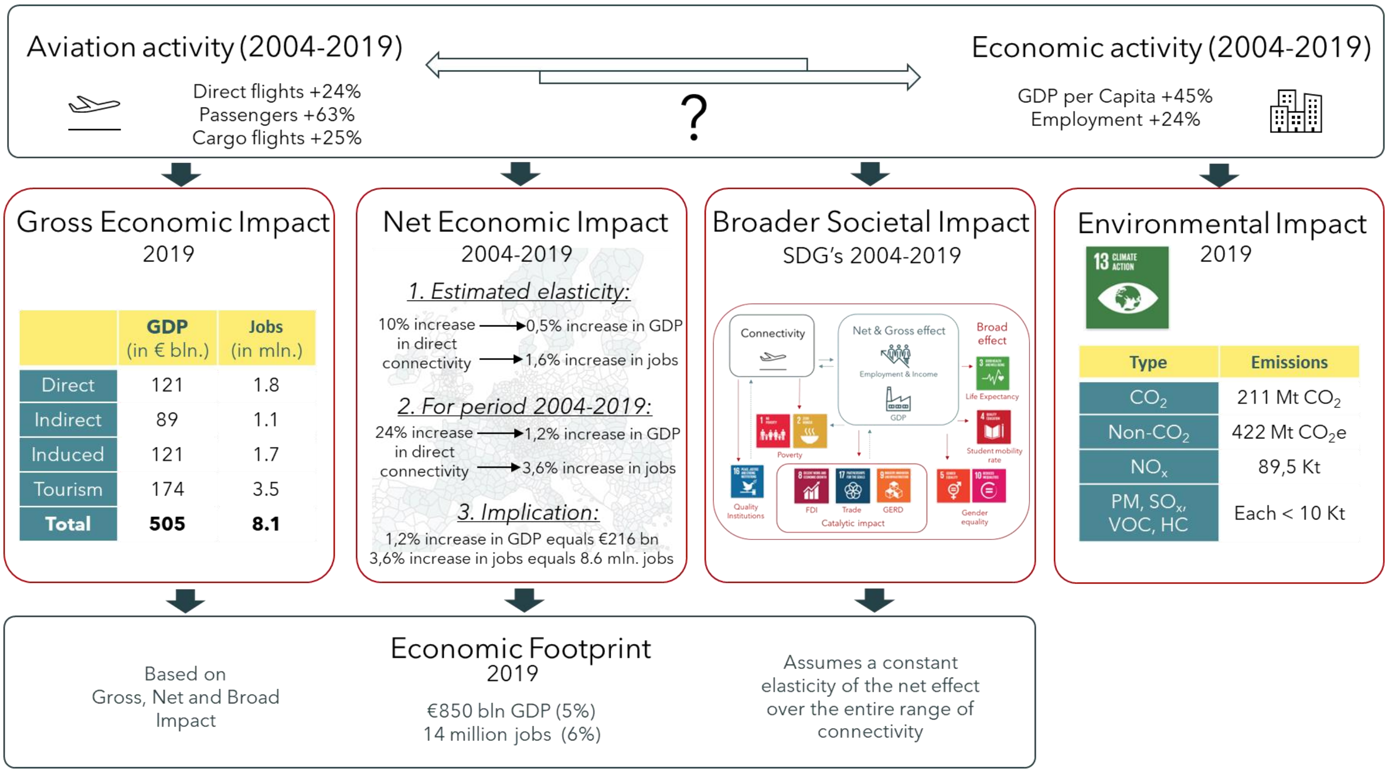
Looking ahead, supply side capacity restrictions, such as airport and airspace capacity, may limit the potential of aviation's economic and social impact. The same holds for supply side factors in the wider economy, such as the (lack of) skilled labor or housing. These limitations may hamper wider economic benefits such as agglomeration and innovation spillovers of aviation.

While this report finds that airport connectivity provides clear economic benefits, these must be considered alongside the associated externalities to ensure sustainable development. For sustainable growth, EU aviation should focus on efficiency and especially on reducing environmental impacts of flight movements, as evidenced by trends in passenger and connectivity growth. The marginal utility of connectivity might diminish, meaning additional connections would yield decreasing benefits.

Although this study has been looking at a period of staggering growth in European air connectivity, one could conjecture that substantial reductions in connectivity would yield opposite results. Substantial reductions in connectivity and market access will likely decrease (the growth rate of) GDP per capita, especially if established catalytic links are disrupted.

This report provides a comprehensive and empirically validated analysis as input for future policy discussions and further research regarding the policy challenges ahead for the European aviation sector.

Figure S.1 The economic and social footprint of European airports



	GDP (in € bln.)	Jobs (in mln.)
Direct	121	1.8
Indirect	89	1.1
Induced	121	1.7
Tourism	174	3.5
Total	**505**	**8.1**

Type	Emissions
CO_2	211 Mt CO_2
Non-CO_2	422 Mt CO_2e
NO_x	89,5 Kt
PM, SO_x, VOC, HC	Each < 10 Kt

Source: SEO Amsterdam Economics (2024)

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1 Introduction & research framework

This study takes a holistic approach to identify and quantify the economic, societal and environmental impact of airports in Europe. Understanding, disentangling and measuring these complex relationships is crucial for stakeholders and policymakers shaping the future of aviation.

1.1 Background, research questions and scope

Background and research questions

SEO (2015) and InterVISTAS (2015) are the most recent studies commissioned by ACI EUROPE on the regional economic impact of airports and date to 2015. For the current study, ACI EUROPE commissioned SEO Amsterdam Economics to analyse the economic and social impact of European airports and air connectivity in recent years. The main research question concerns the empirical measurement of the relationship between airport activity and economic output for defined geographic regions. The study looks at different economic measures such as Gross Domestic Product (GDP), employment and wider economic (agglomeration) benefits. The report also explores the relationship between airport activity on the one hand and social outcomes – such as gender equality and quality of education – and global and local externalities on the other hand. The global and local externalities considered include greenhouse gas emissions, local air pollution and noise pollution.

The empirically validated pathway to measure the regional economic impact of airports air connectivity as explored and applied in the current study, allows for its results and insights to be a cornerstone for stakeholders and policymakers. The outcome can help shape the future of aviation considering the highly relevant and urgent questions about economic, social and environmental challenges.

Spatial scope

The scope of the study includes all ACI EUROPE's member airports. These airports account for nearly all commercial traffic and airports in Europe. Therefore, results presented in this study are representative for European airports. To be precise, the scope includes all countries in which ACI EUROPE's member airports are located, including countries in the European Union, the European Economic Area and a few other countries such as Georgia and Azerbaijan.[1] Whilst the study is representative for Europe, the analysis itself considers the regional economic impact of airports by estimating the effects of an airport within a 150 kilometer radius of the region (NUTS 3 level). This granularity in the approach enables us to discern localized economic effects, accounting for spatial dependencies and regional variations.

Time horizon and COVID-19

Besides the spatial scope, the study focusses on the years 2004 up to 2019. The long time horizon allows for using panel data techniques to isolate the economic and societal impact of airports from other societal and economic trends. COVID-19 is the reason not to include the years after 2019. COVID-19 affected the global economy and travel sector heavily. The effects and reverberations of COVID-19 are detectable in air connectivity with both, lower

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[1] Please see https://www.aci-europe.org/aci-membership/member-airports.html for a current overview of ACI EUROPE's airport members.

levels of connectivity at some airports and a lower share of business travel in the years 2020, 2021, 2022 and arguably in 2023. Even now, in 2024, the most recent ACI EUROPE Connectivity Report, for example, shows that connectivity levels have still not fully recovered (ACI EUROPE, 2024). The lower economic activity associated with airports during and right after COVID-19 is not representative for current or future relevance of aviation and would yield misleading conclusions about the economic and societal impact of European airports. Indeed, the level of economic activity during and right after COVID-19 were merely dictated by government intervention, such as travel bans and economic recovery packages. As a result, throughout the study, 2019 is considered the most recent and most suitable reference year for the relationship between airports and the regional socio-economic outcomes.

1.2 Economic and social impact of air connectivity

Role of airports

Airports are an indispensable link in facilitating long-distance travel and air connectivity. The economic significance of airports, however, extends beyond their direct operational activities, encompassing a variety of impacts throughout the economy. Beyond the immediate value and employment generated within the aviation sector, airports have an indirect influence via their suppliers. For instance, airports rely on a network of suppliers for goods and services, thereby stimulating job creation and value addition in these supporting industries. Furthermore, aviation sector employees and those working for suppliers spend their wages in the national economy. This expenditure supports economic output, thereby positively influencing GDP and employment levels through what is known as the induced impact.

Long-distance travel and air connectivity facilitated through airports correlate with broader economic and societal effects. International air connectivity plays a pivotal role in fostering the growth of tourism, trade, innovation spillovers, and foreign direct investment (FDI), potentially enhancing productivity and competition. This phenomenon is known as the catalytic impact. In addition to its economic implications, airports have a broader societal impact. In the public and policy debate, airport activity is regularly linked to social developments such as cultural exchange, access to education and healthcare services.

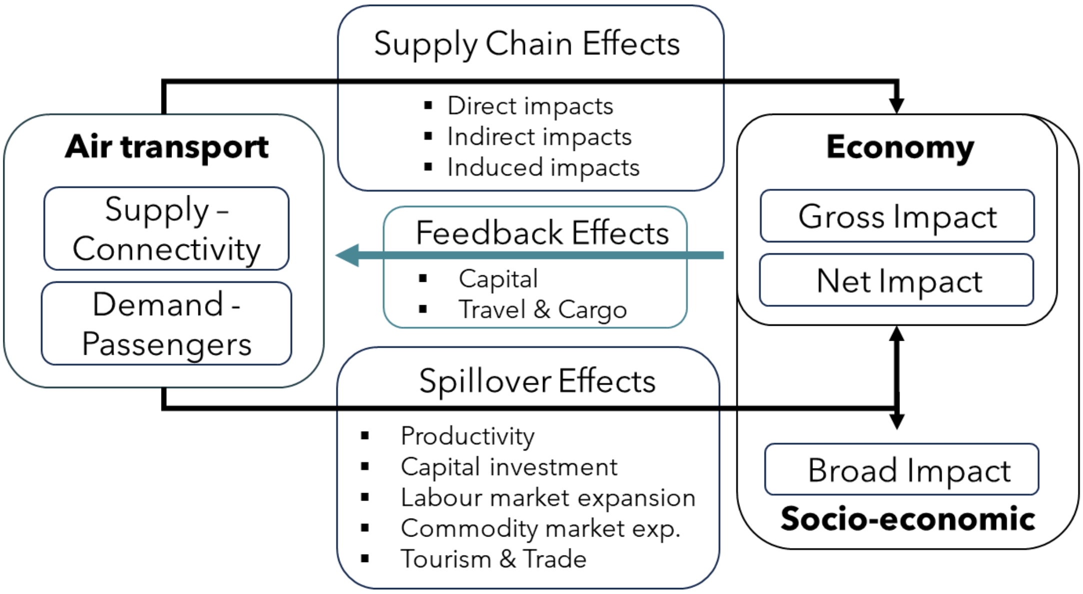
Aviation contributes to global and local externalities, mainly climate change, local air pollution and local noise pollution. Although new aircraft produce significantly less emissions and noise, total emissions and noise levels were still on the rise before COVID-19. Reducing emissions and the climate impacts of aviation presents a much greater challenge. ACI EUROPE together with its European partners are committed to reducing carbon emissions to net zero by 2050. Together with other stakeholders in the European aviation sector, ACI EUROPE developed a roadmap – Destination 2050 – to achieve this target.

Air transport interactions: Supply chain effects, spillover effects and feedback effects

Figure 1.1 shows the stylized interactions of air transport with and within the economy. Air transport can be segmented into two main components: the supply side, represented by connectivity, and the demand side, encompassing passenger volumes. Over the years, numerous studies have explored the economic impacts of air transport. Appendix A provides a full overview of the relevant literature focusing on the effects and measurement of the bi-directional causal interaction between air transport and economic prosperity.

The effects on the economy are divided into the gross impact, the net impact and the broad (social) impact. The gross economic impact refers to the total economic activity generated by the aviation industry within a country. It encompasses all economic interactions, including direct, indirect, and induced effects. The net economic impact is the difference between the gross economic impact and the costs associated with generating that economic activity. It accounts for factors such as leakage (money leaving the local economy), displacement (shifts in spending from one sector to another), and opportunity costs. Net economic impact provides a more accurate assessment of the true economic benefit or loss resulting from the aviation industry, as it considers both the positive and negative effects on the economy. Broad effects refer to the wide-ranging impacts of aviation on various socio-economic variables and the environment. These effects extend beyond direct economic transactions to encompass a diverse array of outcomes that can have significant implications for communities and ecosystems.

Figure 1.1 Interactions between air transport and the economy



Source: SEO Amsterdam Economics, adopted from Zhang and Graham (2020)

The interaction of air transport with the economy runs via three mechanisms: supply chain effects, feedback effects and spillover effects. Supply chain effects basically lead to the gross impact on the economy. Supply chain effects depict how indirect industries utilize the output of a specific industry as inputs in the production of goods or services. Airports also facilitate international business through the connectivity they provide. This may translate into enhanced productivity, trade, tourism, investments et cetera. These effects are commonly referred to as spillover effects and have been examined in various studies (see Appendix A). The dynamic relationship between air transport and the economy encompasses a range of feedback effects. The basic mechanism is economic growth leading to an increase in air travel demand and the additional air travel demand increasing economic activity leading to economic growth. This bi-directional relationship is a key focus in the academic literature, the main lessons learned are applied in the current study (such as advanced econometric techniques) and discussed in Appendix A.

Societal and environmental impact

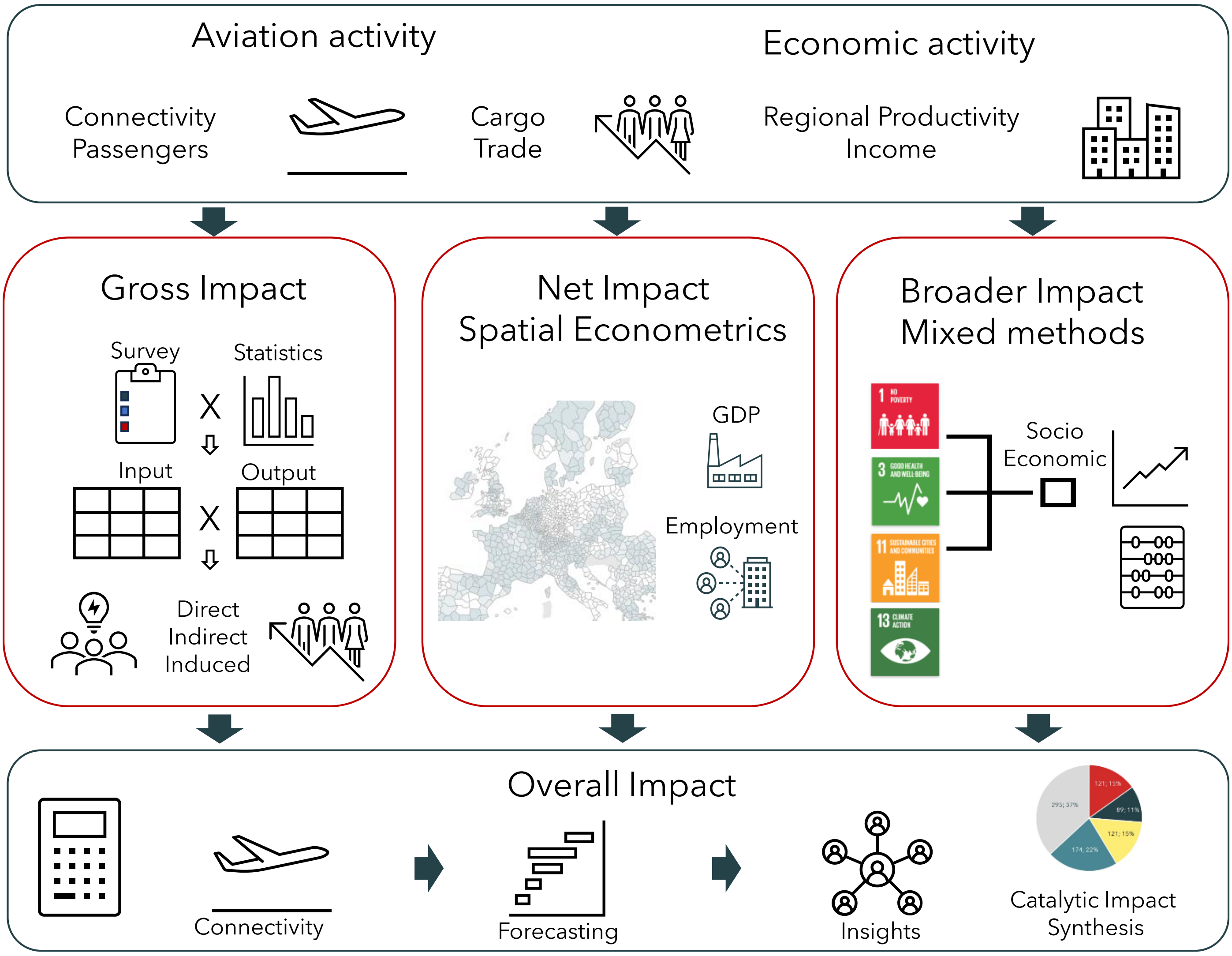
Airports have a broader societal impact that is arguably not fully captured by traditional economic indicators alone. This study explores the broader impact of aviation under the framework of the Sustainable Development Goals stipulated by the United Nations. These goals encompass the collective human aspirations for the following few decades. As such these goals shape EU and national policy and address the challenges of our times in a pro-active and positive light, such as sustainability concerns, regional resilience considerations and political instabilities. Furthermore, an assessment along these goals allows to measure the contribution by airports towards these goals and provides a suitable framework for the analysis.

1.3 Reading guide

Figure 1.2 summarizes the holistic approach, including methods and types of analyses as included in this study:

- **Chapter 2** calculates the contribution of aviation from the ground up to arrive at a gross impact broken down by the total direct, indirect, induced and catalytic impact of European airports in 2019. Furthermore, this chapter introduces briefly describes the collected data amongst ACI EUROPE's airport members.
- **Chapter 3** uses another approach which captures the wider economic contributions that airports enable that are not directly linked to an aviation sector employment or supply chain factor but would not happen without aviation. With that, this chapter switches focus to the net economic impact applying spatial econometrics to disentangle the contribution of airport connectivity and economic growth over time. The chapter furthermore includes a detailed descriptive analysis of the main variables of interest – connectivity, economic growth and employment growth – over time (2014-2019) and over space (NUTS 3 level).
- **Chapter 4** explores the relationship between airports' economic activity on the one hand and societal and environmental impact on the other hand. The first part of this chapter deals with the societal impact exploring the impact of direct connectivity on a wide variety of relevant societal indicators from the Social Development Goals. The second part of this chapter focuses on the environmental impact by analysing in detail and calculating the levels of climate impact (via CO_2 and non-CO_2 emissions), local air pollution and noise of European airports in 2019.
- **Chapter 5** concludes and brings the knowledge of all chapters together. As such it provides the basis to overall impact calculation and the breakdown of the societal and economic impact into its components, in particular the catalytic impact from spillovers, agglomeration and innovation. For external validity, the economic impacts of this report are then compared in relative size to other airport impact studies.

Figure 1.2 A synthesis of regional economic impacts of airports



Source: SEO Amsterdam Economics

2 Gross economic impact

Using survey data and input-output analysis, the results show that the total economic impact of European airports amounts to approximately €505 billion in GDP and 8.1 million jobs. The effect on GDP runs via direct impacts (25%), indirect impacts (25%), induced impacts (33%) and tourism catalytic impact (17%). The wider economic benefits through other catalytic channels are estimated via the net economic approach in Chapter 3.

2.1 Survey data

Survey amongst ACI EUROPE's member airports

To quantify the economic impact of airports, detailed data on their (economic) activities is needed. To collect this necessary data, a survey was conducted among ACI EUROPE's member airports during autumn 2023. In total, 74 member airports responded (response rate of 13%). Of the 50 countries in which ACI EUROPE's member airports are located, 31 are represented in the survey response. Figure 2.1 shows these countries. The airports in these 31 countries represent 85% of total flights in the 50 countries.

Figure 2.1 The survey response captures most countries in which ACI EUROPE's member airports are located

Source: Analysis SEO Amsterdam Economics based on survey among ACI EUROPE's members

Economic activity of airports is mainly measured via employment. Therefore, in the survey members were asked to provide the airport operator employment and the total employment at the airport premises. Furthermore, the airport operator revenues and the number of airport operator issued security ID cards / access control passes were requested. The economic impact is assessed for 2019, the last pre-COVID-19 year, hence the survey asked about data for 2019.

In the survey, the response of small airports (less than 100 direct weekly flights) is underrepresented as shown in Figure B.1 in Appendix B. A total of nine responses were received from small airports. Based on these responses, the estimation of direct employment at small airports is still feasible. However, it is possible that these results are (partly) driven by particularities of the nine small airports that completed the survey.

From survey results to analysing all ACI EUROPE's airport members

To predict employment figures of airports that did not participate in the survey, we use the relationship between direct connectivity (number of direct flights per week) of an airport and its direct employment known from airports who participated in the survey. To do so, we use regression analysis. So, the sample for this regression analysis consists of the airports who responded to the survey. The resulting relationship is then used to predict employment figures of the other airports given their (known) level of direct connectivity. The relationship between direct connectivity and employment for each of the main airport employment categories is established separately. These are:

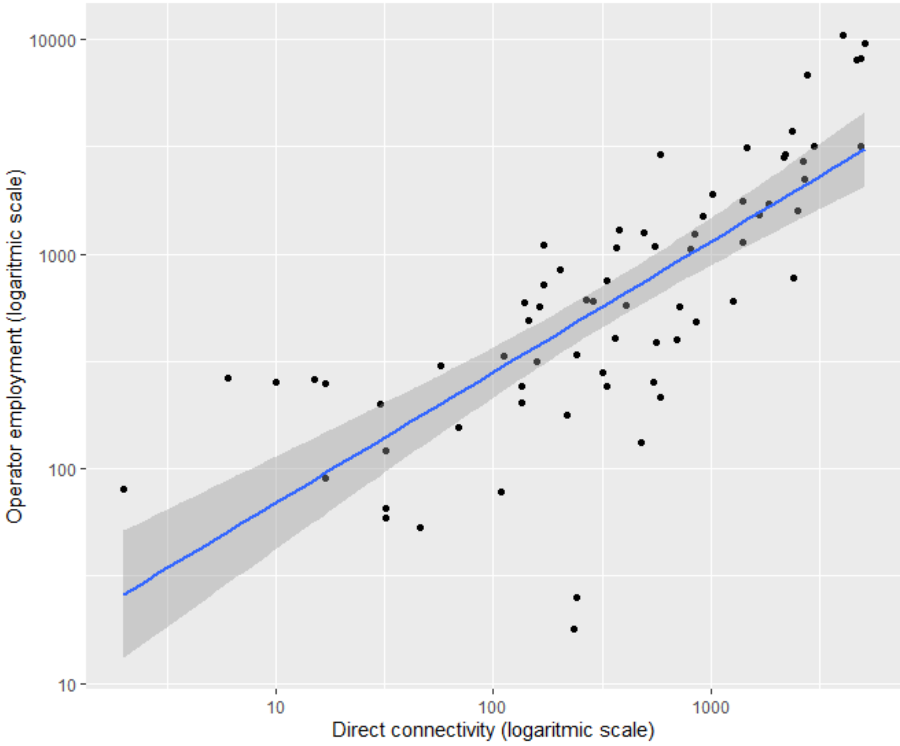
- airport operator;[2]
- airport cleaning and maintenance;
- (passenger and cargo) ground handling;
- passenger screening and other security;
- customs and immigration;
- air traffic control;
- maintenance, repair and overhaul (MRO);
- cockpit & cabin crew stationed at the airport;
- freight forwarders & logistics centres at airport premises;
- retail & restaurants at airport premises;
- hotels at airport premises;
- airport overhead;
- other employment.

The direct connectivity and the airport employment are transformed into logarithms. This allows for the limitation of the impact of outliers on the outcomes and the consideration of economies of scale (i.e., the fact that large airports require fewer operator employees per handled operation/passenger).The survey results show that a strong, positive relationship exists between direct connectivity and employment for each of the employment categories. Direct connectivity is a good predictor for airport employment. For operator employment, the relationship to direct connectivity is depicted in Figure 2.2. The estimated coefficient of this relationship is 0.7%. Accordingly, a 1% increase in direct connectivity results in a 0.7% increase in operator employment. This is an indication for the existence of economies of scale at airport operators, since a 1% increase in direct connectivity results in a less than 1% increase in employment.

We predict airport employment using the number of access control passes issued by the airport operator as a proxy for total airport employment. The survey data show that a strong, positive relationship exists between direct connectivity of an airport and its number of access control passes. The coefficient of the regression equals 1.3% and is statistically significant. Accordingly, a 1% increase in direct connectivity results in a more than 1% increase in total airport employment (proxied by the number of access control passes). This shows that larger airports offer relatively more employment opportunities within their premises, for example in retail, hotels and forward logistics.

[2] For the airport operator employment, we estimate how an airport's direct connectivity, number of passengers and world region is correlated with its direct employment.

Figure 2.2 Relationship between direct connectivity and operator employment indicates economies of scale



Source: Analysis SEO Amsterdam Economics based on survey among ACI EUROPE's members

To predict the total employment for each of the ACI EUROPE's airport members, we use the estimated relationships between direct connectivity of an airport on one hand and total employment and the number of access control passes on the other hand. We ensure that for each airport the employment level prediction based on survey data about airport employment aligns with the prediction based on survey data regarding access control passes. This is done by scaling the former to match the latter. The scaled prediction based on survey data about airport employment is used as the starting point of the gross economic impact analysis.

Interpretation of data coverage ACI EUROPE's airport members

This study examines the activities and impacts of European airports by looking at ACI EUROPE's member airports. These airports were surveyed. ACI EUROPE's member airports account for nearly all commercial traffic and airports in Europe. The aggregate numbers as shown in this report are therefore representative for all airports in Europe, more generally for all countries in which ACI EUROPE's member airports are located and the necessary supplementary data is available (such as the country-specific input-output table). This implies that the reported aggregate figures are conservative and slightly lower than we would end up with if all airports in the relevant countries would be considered. Furthermore, when focussing on smaller geographical areas, the representativity of ACI EUROPE's member airports for all airports in that smaller area may decline. One should keep this in mind when evaluating the results for small countries with only a few airports, such as for example, Slovakia.

2.2 Methodology gross economic impact

Input-output model and four types of impact

The analysis uses an input-output model. Nobel laureate Leontief's input-output model is a widely accepted scientific macroeconomic calculation method. The model is a mathematical method to determine, based on the economic coherence of all sectors in the national economy, how spending and investments by, in this case, employment effects of airport activities, affect that country's national economy via a "snowball effect". The economic coherence is documented in so-called input-output tables. These tables describe the buy and sell relationships between sectors in an economy, showing the product inputs used by a particular sector and those it in turn provides to others. These tables are periodically updated by supra-national agencies, such as Eurostat and the World Bank.

Airports support economic activities in the economy in various ways. The input-output model distinguishes between the following four types of impact:

1. **Direct impact:** Economic output associated with the operation and management of the airport activities. This includes activities by companies at the airports and located near the airport, such as the airport operator, the airlines, ground handlers, 2nd line forwarders[3], security, customs, MRO, ground transportation, et cetera.
2. **Indirect impact:** Economic output related to companies that supply or support the activities at the airports. This includes a wide range of companies. Some examples: wholesalers providing food for airport restaurants or in-flight catering, construction companies, as well as suppliers in the service sectors, such as IT, accounting and travel agents.
3. **Induced impact:** Economic activity resulting from the spending of wages by people directly or indirectly employed through airports. For instance, an airport operator employee spends part of his income in retail outlets, on transportation, on childcare et cetera. This in turn generates economic output in a wide range of sectors of the economy.
4. **(Tourism) catalytic impacts:** Economic impacts resulting from the air connectivity facilitated by airports. International connectivity is an important enabler for developing tourism, trade, and foreign direct investment (FDI) and may enhance productivity and competition.

The indirect, induced and catalytic impacts are modelled through input-output analysis.

Direct impact

The direct added value (GDP) generated by each airport is deduced from its direct employment using the scaled prediction based on survey data for airport employment. This is done by multiplying the direct employment by the applicable labour productivity. The labour productivity figures per sector and per country that we use in this report are sourced from the OECD.

Indirect economic impact

The indirect impact of airports is equal to the added value (GDP) generated by companies that supply to or support the airports' activities. We use 2019 as the reference year. The indirect impact is calculated using input-output

[3] Second line forwarders in aviation are logistics providers who manage and coordinate the transportation of cargo from a primary forwarder to its final destination, often handling complex routing and additional services beyond the initial shipment.

analysis, which requires an input-output table. These tables describing the buy and sell relationships between sectors in an economy are available from the OECD for 35 of the 50 countries in which ACI EUROPE's airport members are active. For the 15 missing countries, the input-output table of a most similar peer country in which ACI EUROPE' airport members are active. Similarity is measured using Harvard's Economic Advancement Index, Table 2.1 shows which countries are used as closest resemblance country.[4]

Using the country-specific input-output tables, we determine which sectors supply or support the activities at the airports. We account for potential leakage to countries outside the countries covered by ACI EUROPE. We also determine which sectors supply to the sectors that supply the activities at the airports, or in other words second-level of supply. For example, agricultural firms providing products to caterers which resale these to airport restaurants. The total sum of this series of intermediate consumption constitutes the indirect GDP. Indirect employment for 2019 is calculated by dividing indirect GDP by average labour productivity per sector and per country.

Table 2.1 For 12 countries the input-output table of the most similar country has been used

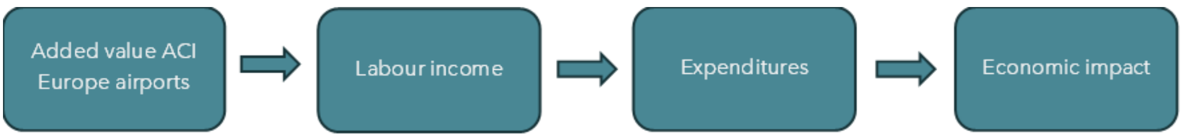
Missing country	Closest resemblance
Albania	Kazakhstan
Armenia	Greece
Belarus	Estonia
Bosnia and Herzegovina	Lithuania
Georgia	Greece
Kosovo	Bulgaria
Moldova	Greece
Montenegro	Bulgaria
North Macedonia	Greece
Serbia	Latvia
Ukraine	Bulgaria
Uzbekistan	Kazakhstan

Source: Analysis SEO Amsterdam Economics based on Harvard's Economic Advancement Index (Harvard University, 2024)

Induced impact

The induced impact is the added value (GDP) resulting from the spending of wages by people directly or indirectly employed through the airports in 2019. The approach is shown in Figure 2.3. Firstly, the labour income supported by the airports is estimated. For this, we use wage share statistics per sector and per world region from OECD regarding 2018, as for later years these statistics were not available. The wage share is the part of added value generated in a sector which is allocated to wages.

Figure 2.3 The induced impact is calculated in four steps



Source: SEO Amsterdam Economics

4 No input-output tables from a similar country are available for Monaco, Faroe Islands and Gibraltar. Airports from these three countries are therefore not included in the indirect economic impact analysis.

Next, we calculate how labour income is spent in the various sectors within the economy using spending statistics. We use spending statistics from OECD per world region in 2019. Part of the labour income goes to taxes. In this analysis we assume that all tax revenues are fully spent within the economy by the government.[5] Induced impact is obtained by estimating the GDP resulting from the spending of labour income. Note that part of the spending takes place outside the European economy. This is not considered in this study, resulting in a minor overestimation of the induced impact.

Induced employment is estimated by dividing induced GDP by average labour productivity per country. Due to limited data availability on spending from capital renumerations directly linked to the airports, we do not take into account the impact on GDP resulting from these specific spendings (such as dividends and interest).

Tourism catalytic impact

The tourism catalytic impact equals the added value (GDP) resulting from the expenditures by air tourists within the European economy in 2019. For each country in which ACI EUROPE's members are active, we estimate air tourists expenditures by multiplying total tourist expenditures within the country by the share of air tourists. This data is provided by the World Tourism Organization (UNWTO).[6] For some countries the share of air tourists is not available. In that case, we use the average share of air tourists in Europe.

Based on country level UNWTO data regarding the expenditure pattern of tourists, we estimate in which sectors the air tourism expenditures end up. Subsequently, tourism catalytic impact is obtained by estimating the GDP supported by these expenditures. Tourism catalytic employment is calculated for each country by dividing the tourism catalytic GDP by the average labour productivity in the tourism intensive sectors.[7] Note that air transport not only makes it possible that tourists spend their money in Europe, but also that European tourists spend their money outside Europe. However, the majority of trips that Europeans take by air are to European countries (SEO & NLR, 2021). As a result, the "leakage of expenditures" via this mechanism is limited.

2.3 Results gross economic impact

Total economic impact

Europe

In 2019, the total economic impact of European airports (direct, indirect, induced and tourism catalytic) amounts to approximately €505 billion in GDP and 8.1 million jobs.[8] Figure 2.4 provides a summary of the four types of impact for the largest included countries. The tourism impact accounts for the largest share of the impact with €174 billion in GDP and 3.5 million jobs, followed by the direct impact with €121 billion in GDP and 1.8 million jobs, and the induced impact with €121 billion in GDP and 1.7 million jobs and the indirect impact with €89 billion in GDP and 1.1 million jobs.

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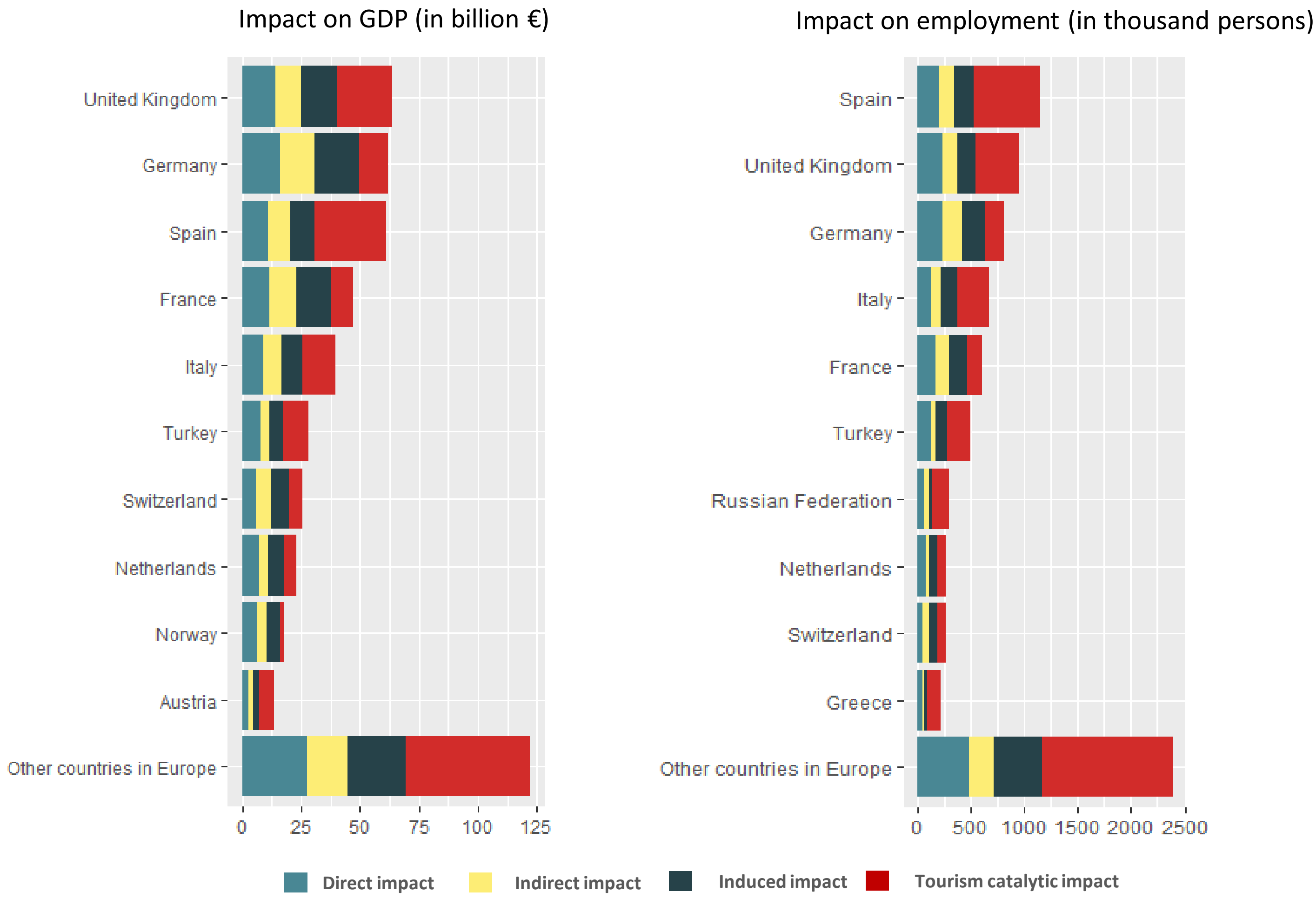
5 Another possibility is that labor income is used for saving. However, saving is deferred spending. For that reason, we do not distinguish between saving and spending.

6 The data does not include domestic tourism and same-day tourism. However, the share of air tourism in these segments is small.

7 The following OECD sectors are regarded as tourism intensive: wholesale and retail trade, transportation and storage, accommodation and food service activities & arts, entertainment and recreation.

8 All monetary outcomes are expressed in 2022 €.

Figure 2.4 The total impact of airports on GDP is highest in the United Kingdom



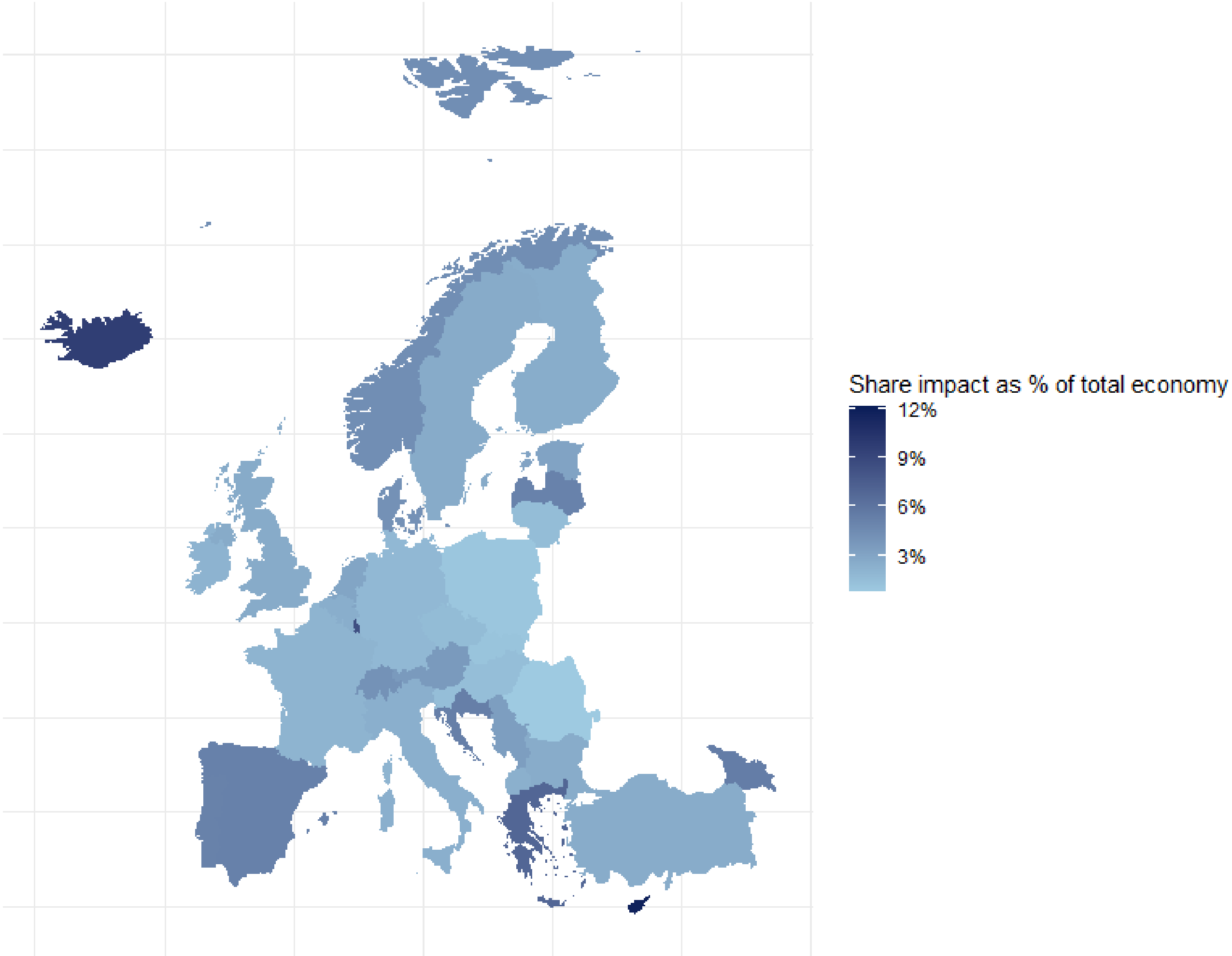
Source: Analysis SEO Amsterdam Economics based on survey among ACI EUROPE's members

Country-specific results

The impact on GDP is highest in the United Kingdom (€64 billion), Germany (€62 billion) and Spain (€61 billion) in 2019. The impact on employment is also the highest in these countries. However, the order of the top-3 is different: Spain (1.1 million jobs), United Kingdom (0.9 million jobs) and Germany (0.8 million jobs). Figure B.10, Figure B.11 and Table B.2 in Appendix B provides detailed country-specific results.

The GDP impact of the airports relative to the total economy size of the included countries amounts to 2.8% in 2019. Figure 2.5 shows for each included country with available data the GDP impact as a percentage of the total economy size of that country. This share is highest for Malta (12.1%), Cyprus (11.8%) and Iceland (9.6%). The employment impact of the airports as a percentage of total employment in the European economy equals 3.5% in 2019. Table B.3 in Appendix B provides detailed results for each country on both the GDP and employment.

Figure 2.5 The relative economic impact of airports measured in GDP is highest in Malta



Source: Analysis SEO Amsterdam Economics based on survey among ACI EUROPE's members

Comparison with previous studies

The estimated direct, indirect and induced impacts are similar to previously published results, see Table 2.2, particularly those from InterVISTAS (2015) and ATAG (2021). The results of ATAG (2021) are higher due to a different geographic and industrial scope. In the ATAG (2021) study also aircraft manufacturing and military are included, but those sectors are not included in the current and the InterVISTAS study.

Table 2.2 Similar results of direct, indirect and induced impact estimated by SEO, ATAG and InterVISTAS

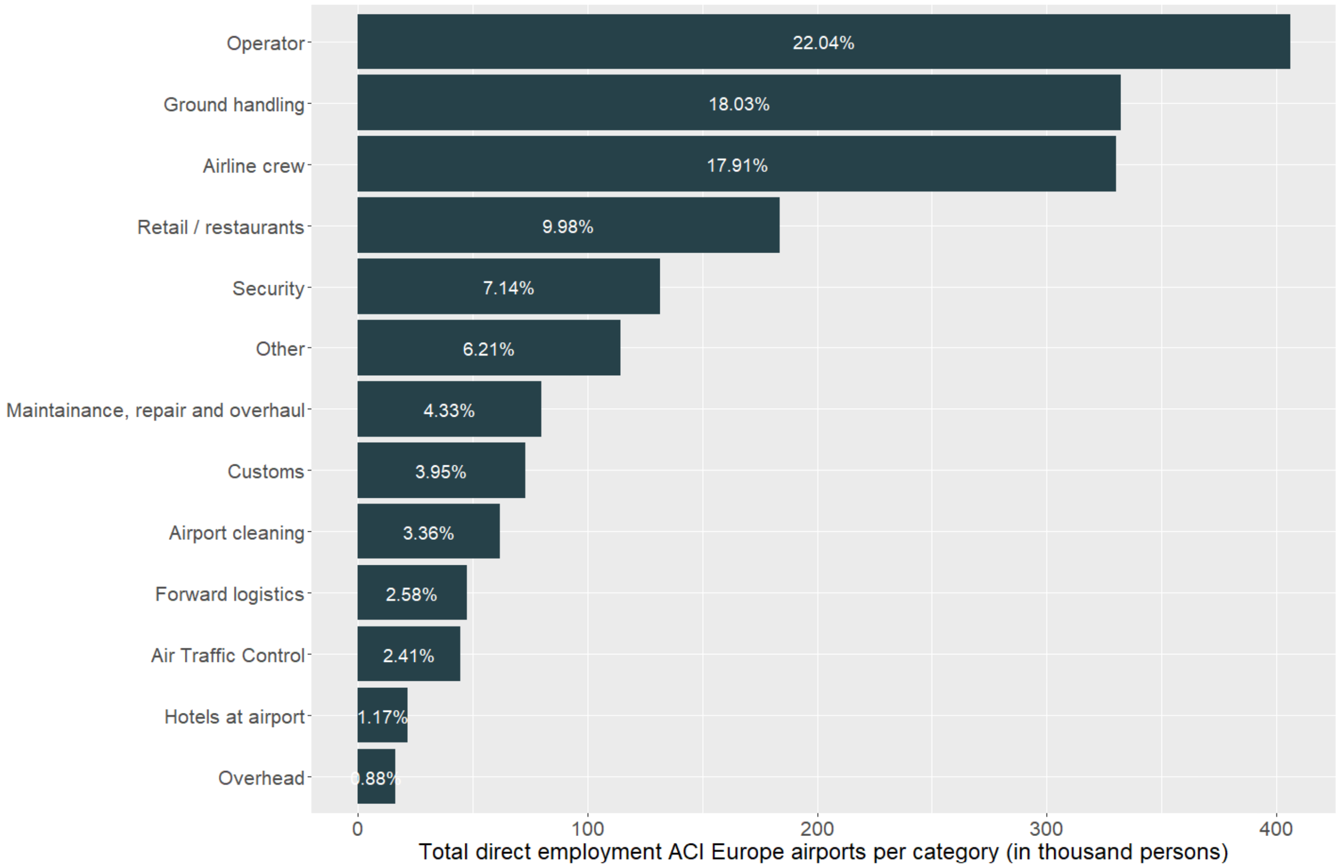
	SEO (2024)	ATAG (2021)	InterVISTAS (2015)
GDP in €bn			
Direct GDP	121	210	102
Indirect GDP	89	205	70
Induced GDP	120	152	76
Employment			
Direct Jobs	1,843,000	2,700,000	1,696,200
Indirect Jobs	1,126,000	3,000,000	1,353,100
Induced Jobs	1,679,000	2,200,000	1,401,100

Source: SEO Amsterdam Economics based on ATAG (2021) and InterVISTAS (2015)

Direct economic impact

Around 121 billion euros in GDP and 1.8 million jobs are directly related to airports in 2019, as shown in detail in Figure B.1 and Figure B.3 in Appendix B. Airport operator (0.4 million jobs), ground handling (0.3 million jobs) and airline crew (0.3 million jobs) are the most important job categories as depicted in Figure 2.6.[9] These three categories together account for 58% of the total direct employment. The direct impact on GDP and employment is highest in Germany in 2019, namely 16 billion euros in GDP and 0.2 million jobs.

Figure 2.6 Airport operators account for the largest share of direct employment at the airports



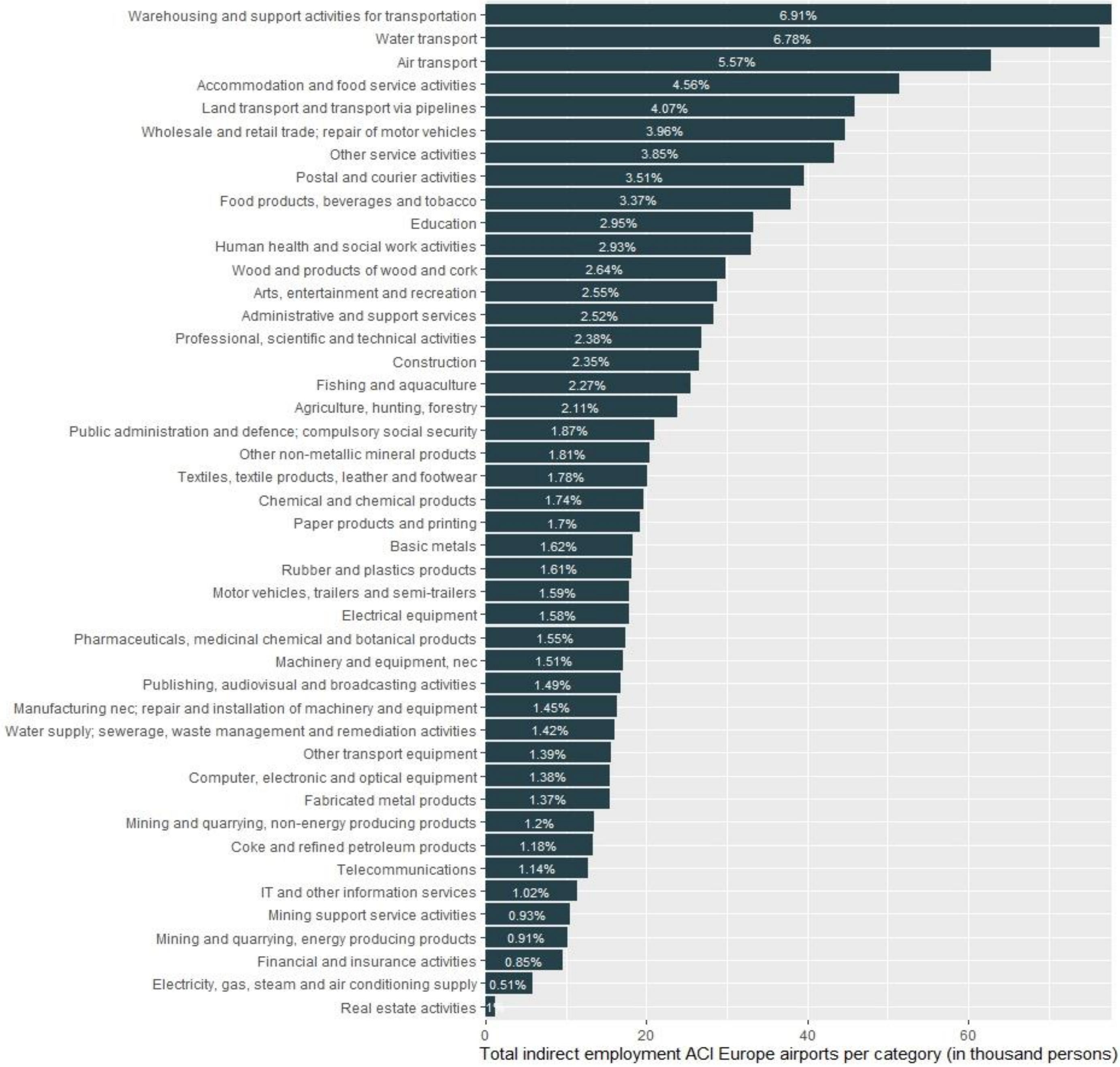
Source: Analysis SEO Amsterdam Economics based on survey among ACI EUROPE's members

Indirect impact

The airports also support GDP and employment by purchasing goods and services from suppliers (indirect impact). This impact is estimated through an Input-Output analysis. In 2019, the indirect economic impact of the airports amounts to around 89 billion euros in GDP and 1.1 million jobs. For both GDP and employment, the indirect impact is highest in Germany and amounts to 14 billion euros GDP and 0.2 million jobs. The details are provided in Figure B.4 and Figure B.5 in Appendix B. The indirect employment impact of the airports mostly ends up in the sector "Warehousing and support activities for transportation" with almost 80,000 jobs as shown in Figure 2.7. Other important sectors are "Water transport" and "Air transport".

9 The category airline crew is based on the narrow definition of cockpit and cabin crew stationed at the respective airport and therefore does not include visiting airline crews and employment at airline headquarters.

Figure 2.7 “Warehousing and support activities for transportation” has the largest indirect employment impact



Source: Analysis SEO Amsterdam Economics based on survey among ACI EUROPE’s members

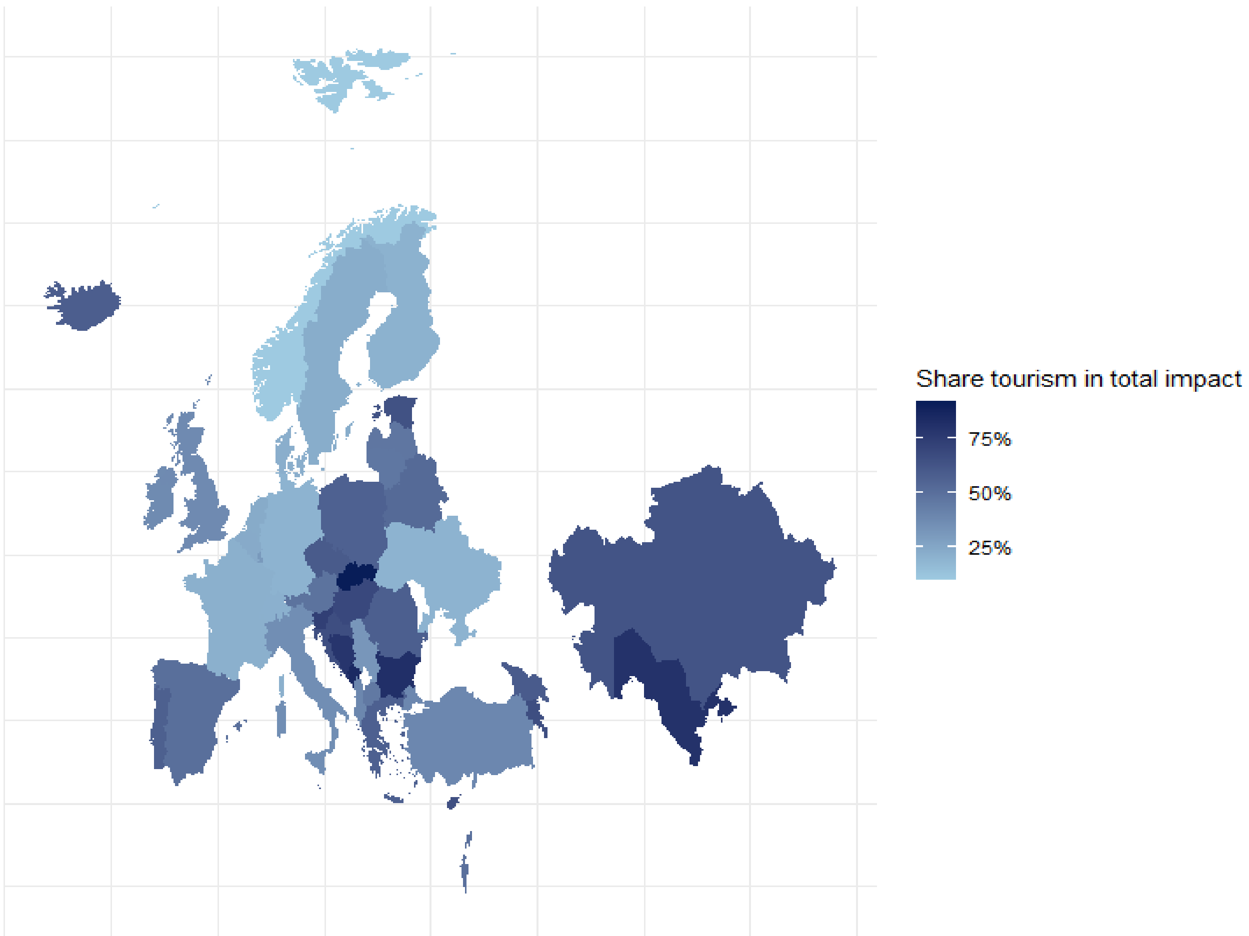
Induced impact

Spending of wages by individuals directly or indirectly employed through airports also contributes to job creation and GDP growth within the European economy. These induced impacts are estimated based on spending statistics from OECD. In 2019 the induced economic impact of the airports is approximately 120 billion euros in GDP and 1.7 million jobs. Figure B.6 and Figure B.7 in Appendix B provide further details. In Germany, the United Kingdom, France and Spain the induced impact is the highest. Around 40% of the impact is through the government spending of taxes paid by employees directly or indirectly employed through the airports.

Tourism catalytic impact

The airports also contribute to the economy by enabling tourists to visit countries in Europe and make expenses there. Tourism relies heavily on air transport and has a substantial impact on GDP and employment (Lenzen, et al., 2018). In 2019, air tourism sustains approximately €174 billion in GDP and 3.5 million jobs in the included countries. The impact of air tourism on GDP and employment is highest for Spain, the United Kingdom and Italy. Figure B.8 and Figure B.9 in Appendix B provide details. Figure 2.8 shows the share of the tourism catalytic impact in the total economic impact. This share is highest for Slovakia (92%), Montenegro (85%) and Bulgaria (82%). The share is lowest for Norway (10%), Germany (20%) and Ukraine (20%).[10]

Figure 2.8 The share of the tourism catalytic impact is highest in Slovakia and lowest in Norway



Source: Analysis SEO Amsterdam Economics based on survey among ACI EUROPE's members

10 For Slovakia, the direct, indirect and induced impact is the lowest of all countries (measured relative to economy size). This is due to the focus on ACI EUROPE's airport members. From the four airports in Slovakia, two are not members of ACI EUROPE. Hence, for Slovakia the analysis based on the members is most likely not or less representative than for the other included countries.

3 Net economic impact

The analysis uses econometric models to identify and quantify the additional net economic impact of airports, whilst controlling for wider regional economic factors such as prices and labour markets. The estimation results show that a 10% increase in direct connectivity positively impacts GDP per capita by 0.47% and impacts employment by 1.6%. For cargo flights a positive correlation is found, but the direction of causality remains unclear.

3.1 Methodology net economic impact

The relationships between connectivity, passengers and cargo flights and key economic indicators such as GDP per capita and employment can be explored via regression analysis. The standard approach is estimating so-called Ordinary Least Squares models. These models might return biased estimates due to endogeneity. This is a bi-directional causal relationship between the endogenous variables and the dependent variable. To address this endogeneity issue, two-stage least squares estimations with lagged endogenous variables as instrumental variables are considered here. The results of the models addressing endogeneity are paramount for inference and policy implications, as they offer a more rigorous approach identifying causal effects.

The focus of this study is on the relationship between connectivity and GDP. Therefore, the main specification has the following form:

$$log(GDP_{it}) = \beta_0 + \beta_1 \times \log\,(direct\ connectivity_{it}) + \beta_2 \times year_t + \beta_3 \times NUTS3_i + e_{it},$$

where the dependent variable $log(GDP_{it})$, is the natural logarithm of GDP per capita in NUTS 3 region i and year t. The main independent variable of interest $\log\,(direct\ connectivity_{it})$ is the natural logarithm of direct connectivity in 150km radius of a NUTS 3 region. Additionally, year fixed effects $year_t$ are included to correct for time trends and NUTS 3 regional fixed effects $nuts3_i$ are included to correct for time-invariant regional characteristics.

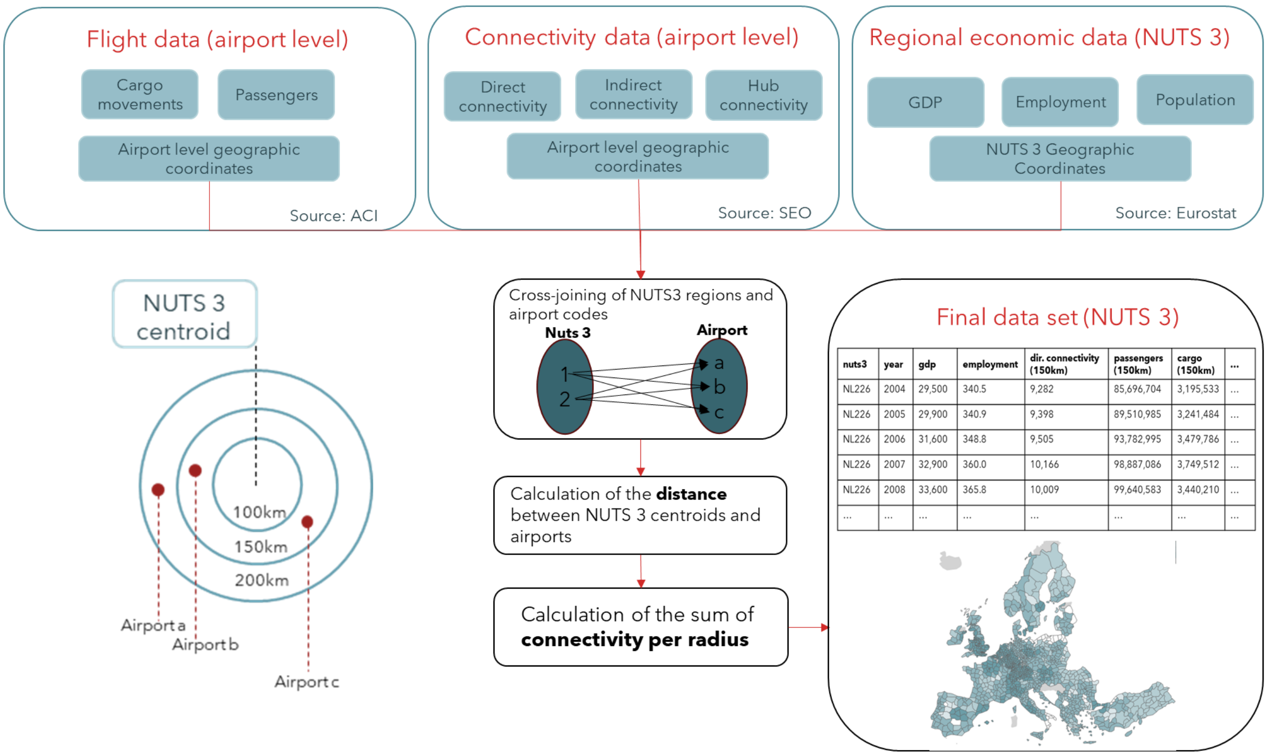
The main parameter of interest is β_1. This parameter denotes the (causal) relationship between airports' main output – connectivity – and key economic indicators. In the main model, the third lag of the endogenous variable (i.e. connectivity or passengers) is used as an instrument. Lagged connectivity, lagged passengers and historical infrastructure were considered as instruments. Other potential instruments were either unavailable or not applicable. More explanation and details on the econometric methodology are provided in Appendix C.

3.2 Descriptive analysis main variables of interest

Data

To combine aviation and economic data, data from various sources are combined into one dataset. Figure 3.1 gives an overview. This dataset includes data on connectivity, passenger and cargo flights within 150km from the centroid of a Nomenclature of territorial units for statistics third level (NUTS 3) region as well as population, GDP and employment per NUTS 3 region. The dataset spans from 2004 to 2019, with observations on the NUTS 3-year level.

Figure 3.1 Data from several sources is combined into one dataset on NUTS3 level



Source: SEO Amsterdam Economics

This panel dataset is to a large extent balanced, meaning that there are only few missing observations for GDP and employment as countries outside the EEA do not always have all information on the Nuts 3 regional level. In order to deal with this, it is assumed that these countries are one Nuts 3 region and national-level information (commonly available) is being utilized. Furthermore, missing observations for connectivity on airport level have been imputed by a linear model (in total 1,273 observations). See Appendix C for a more detailed description of the construction of the dataset and the imputation of missing connectivity data.

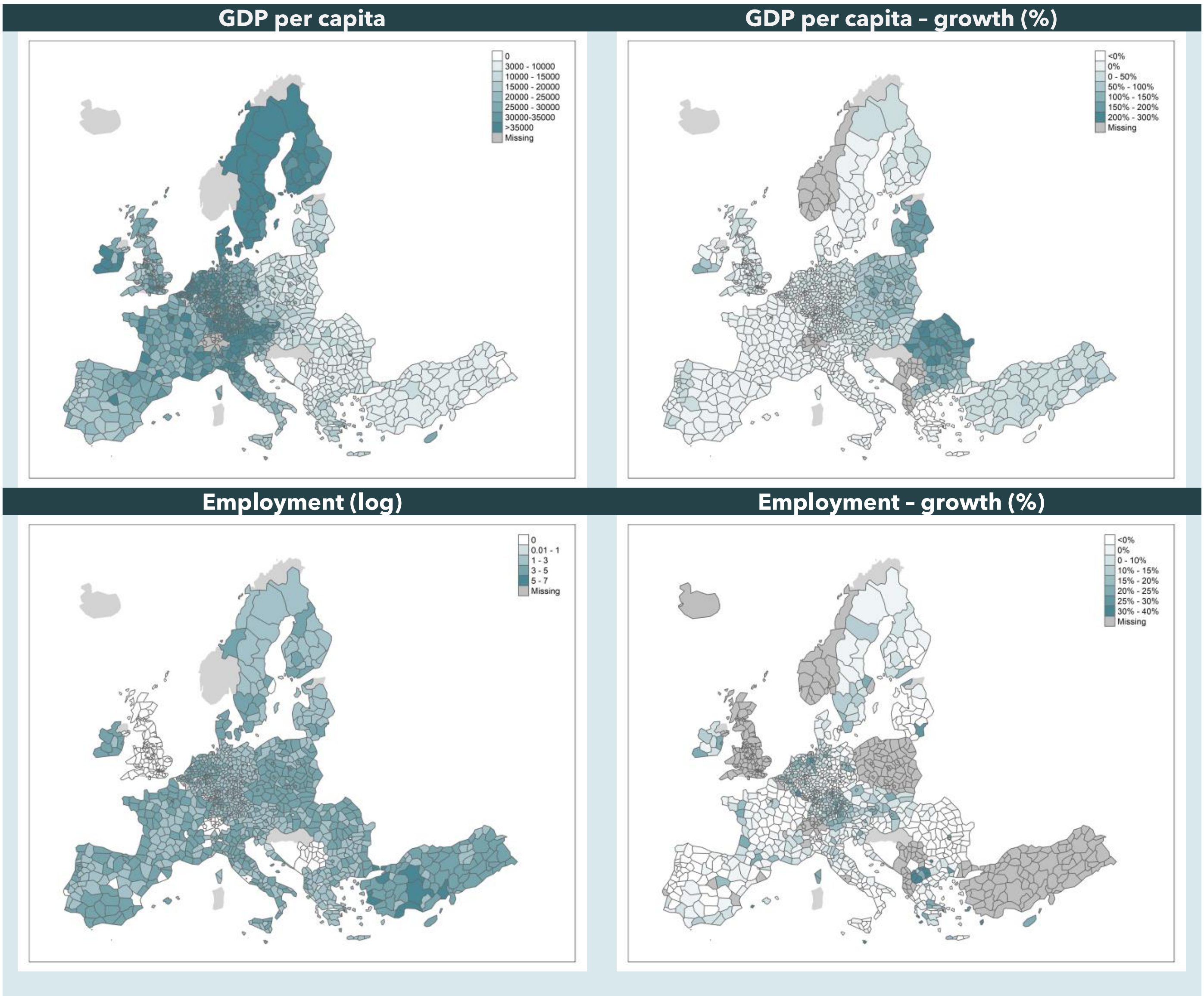
Descriptives dependent variables: GDP per capita and Employment

The dependent variables considered in the net economic impact analysis are GDP per capita and employment. In other words, the model is used to explain (changes in) GDP or employment via (changes in) airport output measures, such as connectivity, controlling for year and NUTS 3 region fixed effects. The dependent variables are defined as:

- *GDP per capita (log):* Natural logarithm of the average GDP per capita within 150km from the centroid of a NUTS 3 region. GDP per capita is measured in Euros.
- *Employment (log):* Natural logarithm of employment in 100.000 persons within 150km from the centroid of a NUTS 3 region.

Growth in GDP per capita differs across regions. Figure 3.2 shows that growth was lowest in northern Europe, while GDP growth was highest in eastern Europe over het period 2004 to 2019. It is observable that growth in employment is mainly taking place in central Europe, driven by migration from Eastern European countries facilitated by European integration (Adler et al., 2020).

Figure 3.2 GDP growth is highest in eastern Europe while employment growth takes place in central Europe



Source: Analysis SEO Amsterdam Economic based on Eurostat

Descriptives independent variables: Connectivity and Passengers

The analysis considers various independent variables, four of them basically boil down to air connectivity and the last one considers passenger levels:

- *Direct connectivity (log):* The number of direct flights per week departing from airports located within 150km from the centroid of a NUTS 3 region .[11]

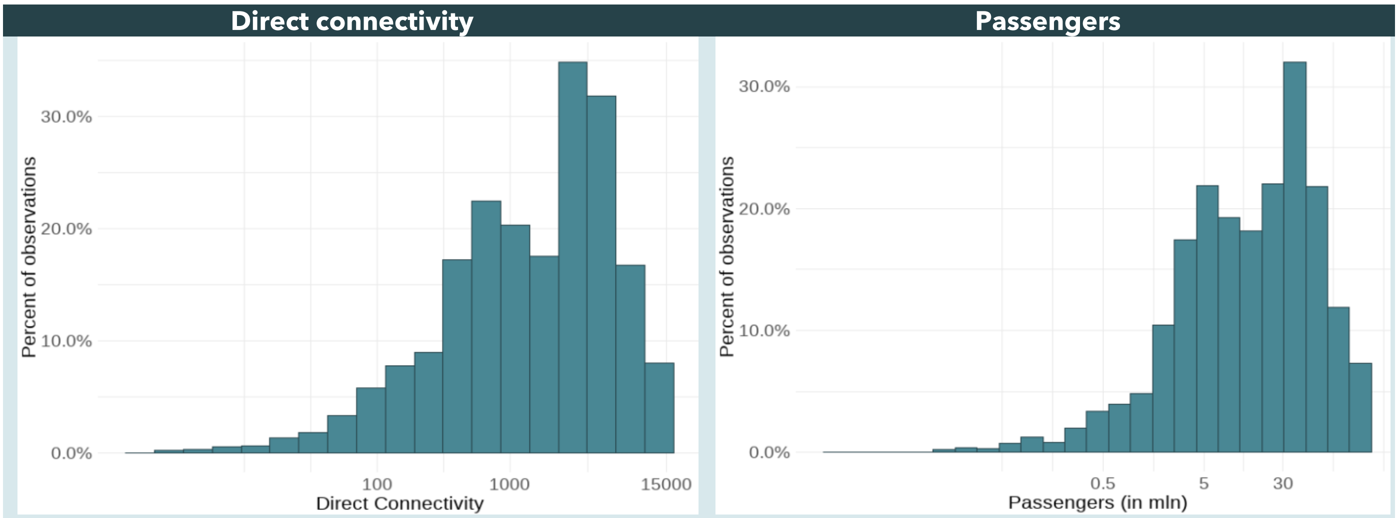
[11] Different spatial scales (e.g., 50km, 100km) have been tried out, with the 150km radius providing the most stable results. The size of airport catchment areas depends on regional and airport characteristics. Catchment area values between 100kmand 150km are generally accepted in the literature (Lieshout, 2012).

- *Indirect connectivity (log):* The number of indirect flights per week departing from airports located within 150km from the centroid of a NUTS 3 region.
- *Airport connectivity (log):* The combined total of direct and indirect connectivity departing from airports within 150km from the centroid of a NUTS 3 region.
- *Hub connectivity (log):* The number of hub connections per week via airports located within 150km from the centroid of a NUTS 3 region.
- *Number of passengers (log):* Number of total passengers per year arriving and departing from airports within 150km from the centroid of a NUTS 3 region.

The air connectivity measures used here are in line with the direct, indirect, total and hub connectivity figures reported by ACI EUROPE in their yearly Airport Industry Connectivity Report. The connectivity figures, hence, are determined based on the SEO-NetScan model.[12]

Due to skewness in the level data (indicating that there are many NUTS 3 regions with very low connectivity in the dataset), the natural logarithm of all variables is used. Additionally, this transformation simplifies the interpretation of regression results: coefficients on the natural log scale represent relative differences ('elasticities'). Following the standard in empirical economic research, in Figure 3.3 the log transformation has been applied to show the distribution of the values of direct connectivity and passengers (after log transformation).

Figure 3.3 Log transformation reduces skewness in connectivity and passenger data



Note: Direct connectivity (per week) and passengers (per year) in a 150km radius. The x-axis scale reports the log transformed variables in levels (i.e., the original unit of observation)

Source: Analysis SEO Amsterdam Economic

A total of 97% of the NUTS3 regions in our data have at least one airport within 150km radius (see Table 3.1). Of these regions, 77% have a small airport, 83% have a medium size airport, and 57% have a large airport.[13] 89% of the NUTS 3 regions have an airport providing hub connectivity – i.e. a hub airport – within 150km radius. Small and

12 See https://www.aci-europe.org/air-connectivity.html.

13 The following categorization for airport sizes has been used: 1 – 99 direct flights a week is a small airport, 100 – 1000 direct flights a week is a medium size airport, 1000 direct flights per week is a large airport, see also Figure B.1 in Appendix B.

medium sized airports usually exist in regions without large airports and provide connectivity to regions where large airports are absent (see Figure C.2 in Appendix C).

Table 3.1 97% of the NUTS 3 regions have an airport within 150km radius.

NUTS 3 regions with airport in 150km radius (%)	NUTS 3 regions with a small airport in 150km radius (%)	NUTS 3 regions with a medium size airport in 150km radius (%)	NUTS 3 regions with a large airport in 150km radius (%)	NUTS 3 regions with a hub airport in 150km radius (%)
96.9	77.3	83.3	56.9	89.4

Source: Analysis SEO Amsterdam Economic

Connectivity, the number of passengers and the growth rates between 2004 and 2019 are presented in maps in Figure 3.5. There are high levels of connectivity for urban and economic centers. Direct connectivity is highest in the region Buckinghamshire, close to London. There are six airports located within 150km radius from this region. They jointly provide 14,238 flights per week in 2019, of which, for example, 4,676 flights are operated at London Heathrow airport. Table C.2, Table C.3 and Figure C.3 in Appendix C provide further summary statistics on the connectivity variables.

Connectivity growth is centered on (Southern) Eastern European countries that have economic growth from European integration. Connectivity growth is highest in the Turkish region Bilecik, which has several airports within 150km radius that saw marked growth over the past two decades (i.e. Atatürk International Airport, which has now been replaced by Istanbul Grand Airport, Sabiha Gökçen International Airport and Adnan Menderes International Airport). Furthermore, there is high connectivity growth in regions with high levels of tourism in Southern Europe. For example, the region Ragusa in Sicilia experienced high connectivity growth (approximately 400% increase) in the period from 2004 to 2019. Connectivity growth is limited or even absent for economic centers and large airports due to lack of available slots for landing and take-off. In slot constrained regions growth will be from aircraft size and load factor instead of connectivity.

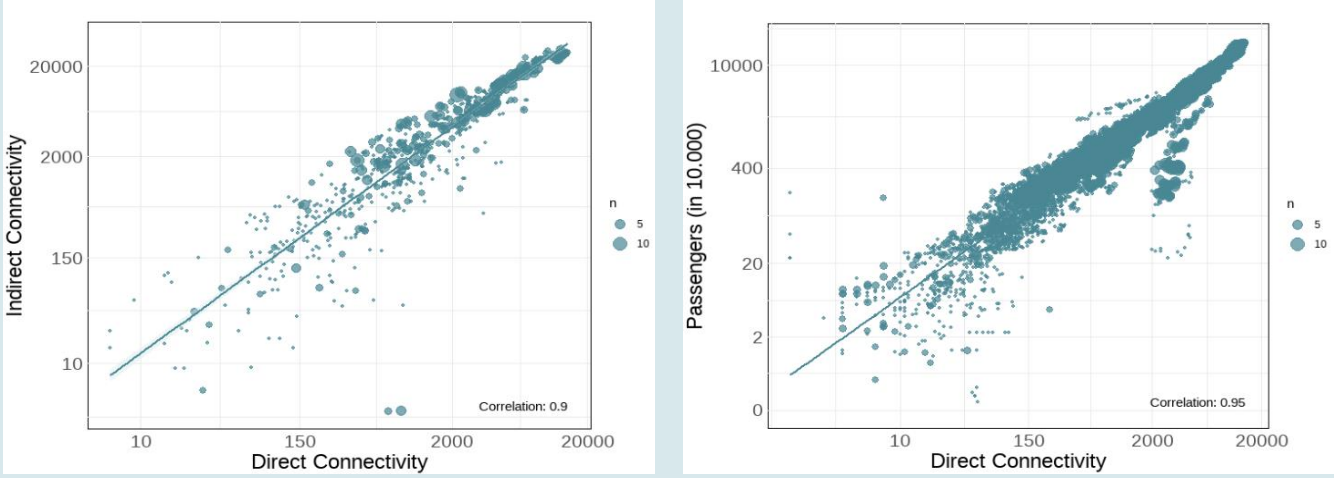
These observations may be indicative of a reshuffle in travel patterns, potentially reflecting a shift where destinations in the industrial belt transition towards regions experiencing strong economic growth. Alternatively, it could signify a substantial rise in international travel originating from these airports.

It is observable that the growth in the number of passengers is higher than the growth in direct connectivity. For example, in 150km radius around the NUTS 3 region where Schiphol airport is located, passenger numbers increased by 81% between 2004 and 2019, while direct connectivity went up by 40%.

Direct, Indirect and airport connectivity are highly correlated. Including more than one of these correlated variables in one model specification would yield results affected by multicollinearity which in turn can lead to misinterpretation of the results. The correlation plots in Figure 3.4 clearly show that it is not wise to put direct and indirect or direct and airport connectivity in one model as there is not enough varying information. Furthermore, we observe heteroscedasticity at the lower end of direct and indirect connectivity. This means that for small and medium airports there is a high(er) variety of how much the airport would gain from adding more direct flight connectivity in terms of indirect connectivity. For large airports, more direct connectivity would lead to average improvements in indirect and airport connectivity as this appears to be a linear relationship. Log transformation of connectivity deals with the heteroskedasticity at lower connectivity levels, while using only one measure of connectivity in the regression ameliorates the potential multicollinearity issue of including highly correlated variables.

Figure 3.4 Connectivity and passengers are highly correlated (96%).

Correlation of direct connectivity and indirect connectivity (2019)	Correlation of direct connectivity and passengers (2019)

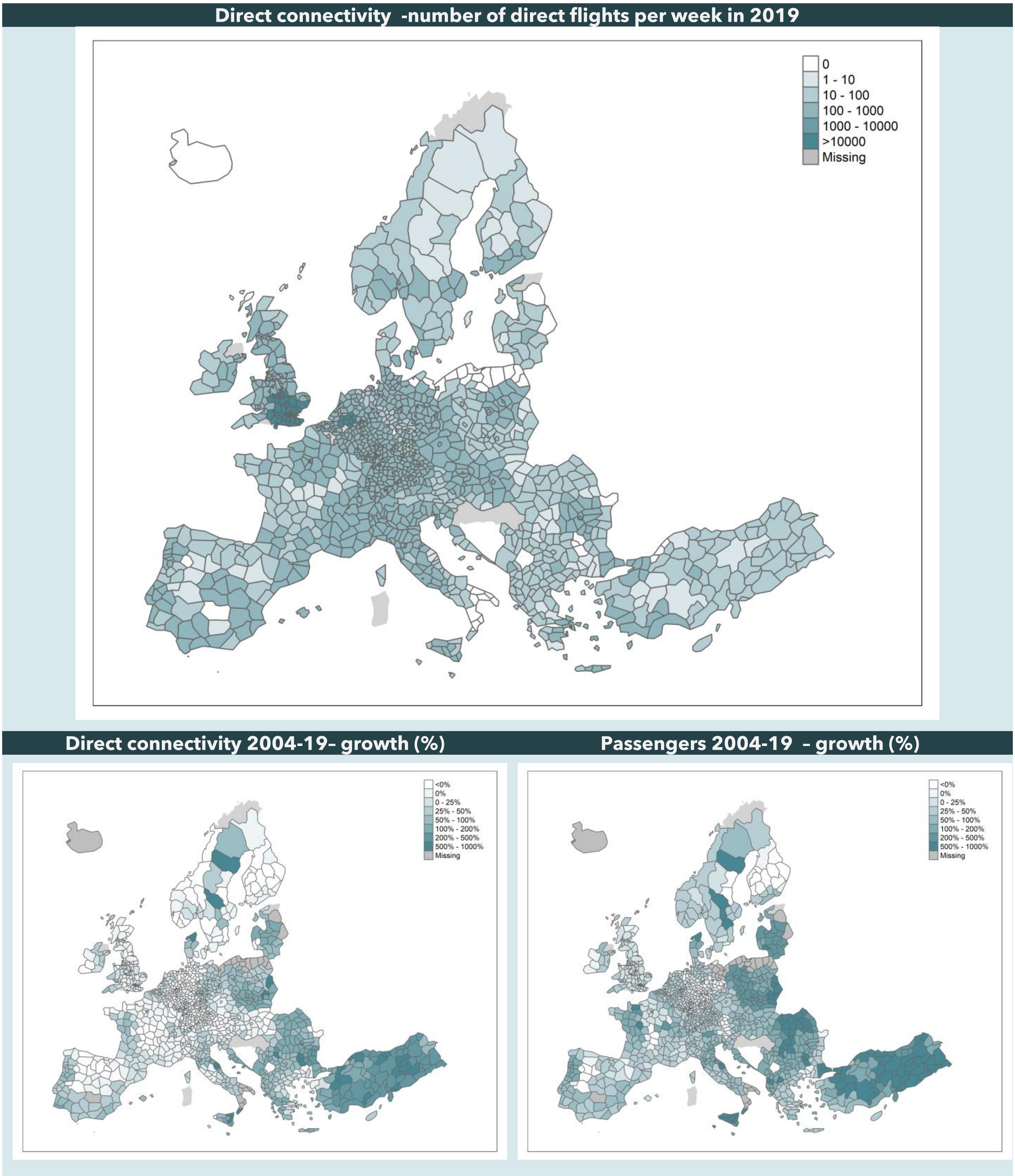


Note: Direct and indirect connectivity (per week) and passengers (per year) in a 150km radius. The x-axis scale reports the log transformed variables in levels (i.e., the original unit of observation)

Source: Analysis SEO Amsterdam Economic

Passengers and connectivity are core to this analysis. While this is intuitively apparent, academic literature affirms that there is strong bi-directional causality of GDP and the number of passengers (Marazzo, Scherre, & Fernandes, 2010; Van De Vijver, 2014; Hakim & Merkert, 2016; Fernandes & Pacheco, 2010). On the one hand, higher passenger volumes stimulate GDP, on the other hand a higher GDP is directly associated with a higher number of passengers due to increased disposable income, business travel and tourism. For connectivity there is also a bi-directional causal relationship of GDP and connectivity as attested in the literature, see Appendix A. The causal relationship from GDP to connectivity could be less evident than that for passengers. Since upgrades to infrastructure to accommodate direct connectivity might be lumpier (in terms of runways) than that of passenger accommodation through terminal upgrades as well as fleet expansion by airlines, therefore rendering an associated reverse effect more long-term. We deal with those endogeneity concerns from the bi-directional relationship with using a two stage instrument variable estimation technique in form of a control function.

Figure 3.5 Connectivity and passenger growth is centered on Eastern European countries



Source: Analysis SEO Amsterdam Economic

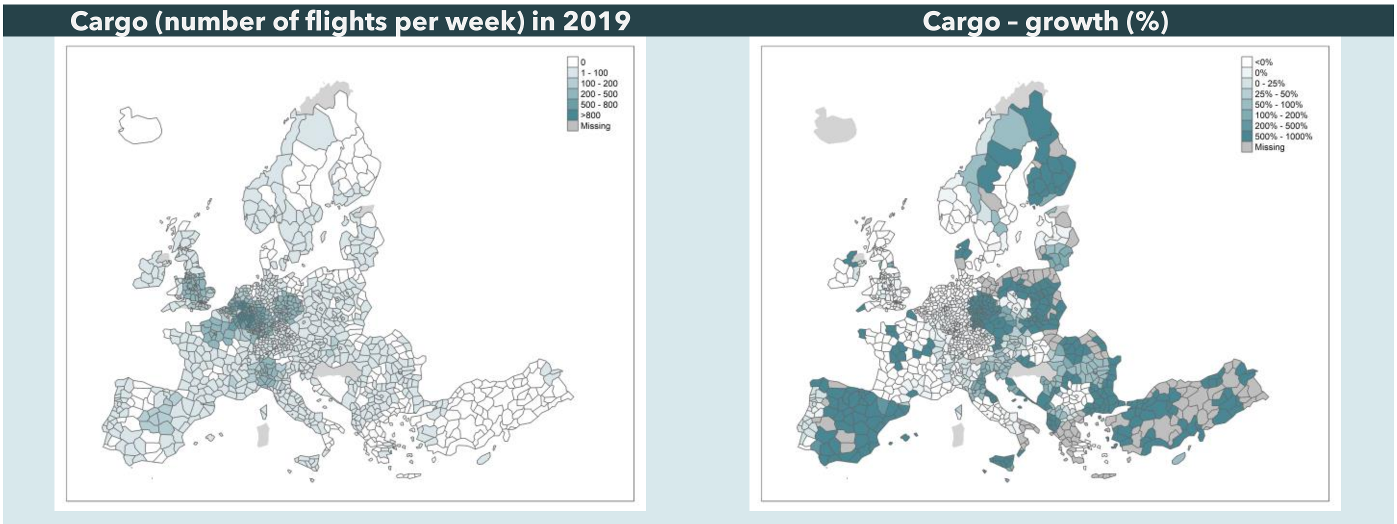
Descriptives independent variables: Cargo movements

Including the effect of cargo flights on GDP is crucial for understanding the role of air freight in driving economic growth, facilitating international trade, and enhancing supply chain efficiency. Therefore, alongside connectivity and passengers, cargo flights are used as an independent variable:

- Cargo movements (log): The number of cargo flights departing from airports within 150km from the centroid of a NUTS 3 region.[14]

In contrast to passenger flights, pure cargo flights are limited to specific airports. Airports that operate cargo flights are centrally located, allowing for swift onward transportation at minimal time cost (see Figure 3.6). This setup promotes centralized operations and economies of scale, aligning with footloose operation principles. Cargo-centric airports require affordable land and labor to remain competitive. Airports with good market access and centrality are better positioned to attract cargo traffic and facilitate efficient distribution, contributing to their overall competitiveness in the cargo transportation industry.

Figure 3.6 Cargo flights are limited to specific airports



Source: Analysis SEO Amsterdam Economics

Correlation over time between all variables

Connectivity, the number of passengers, cargo and GDP are highly correlated and develop similarly over time (Figure 3.7). However, passenger growth (63%) is leading GDP growth (45%), connectivity growth (24%) and cargo growth (25%). Direct connectivity and cargo see an extended effect from the 2008 financial crisis than passengers and GDP. From 2014 onwards, connectivity once more increases together with cargo connectivity.

[14] The data were provided by ACI World - Annual World Data 2000-2022. We use the number of cargo flights because freight in tons is highly correlated with direct flights due to belly freight.

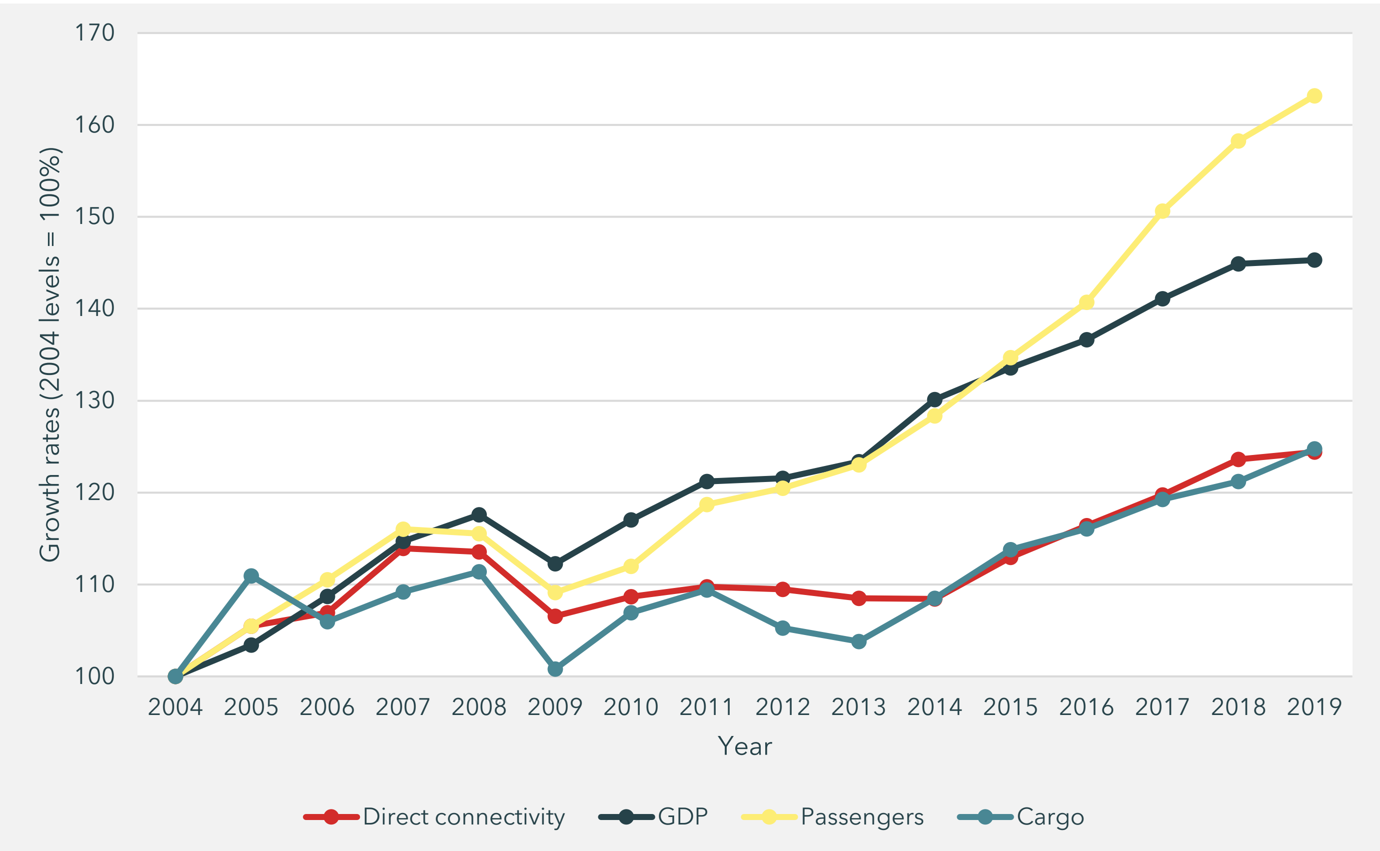
3.3 Results net economic impact

Main estimates

For the main estimation, two stage least squares models (2SLS) are used to estimate the causal effect of direct connectivity in 150km radius on GDP per capita and employment. The regression results show that direct connectivity on average has a positive effect on GDP per capita.

A 10% increase in direct connectivity leads to a GDP increase by 0.47% as shown in first column of Table 3.2. The effect of direct connectivity in 150km radius on employment is estimated and the results are shown in the second column of the table. This model contains fewer observations due to missing data in employment. An increase in direct connectivity raises employment. The effect on employment is higher than on GDP per capita but in line with the literature, e.g. (Brueckner, 2003), (Green, 2007), (Lakew & Bilotkach, 2018), (McGraw, 2020). This larger effect on employment than GDP indicates employment creation in the service industry related as increased connectivity benefits labor-intensive industries like hospitality, tourism, and services, leading to more job opportunities and therefore higher employment in these sectors.

Figure 3.7 Relationship between connectivity, passengers, cargo flights and GDP per capita over time



Source: Analysis SEO Amsterdam Economics

The analysis of the net economic impact reveals that for every 10% increase in connectivity, there is a corresponding 0.5% increase in GDP and a 1.6% increase in employment. Between 2004 and 2019, the overall connectivity of European airports grew by an average of 24%. Applying the elasticity estimate to this period, this 24% rise in connectivity is associated with a significant economic contribution, amounting to approximately €216 billion in GDP and the creation of between 8.6 million jobs. This highlights the critical role that enhanced connectivity plays in driving economic growth and employment across Europe.

Table 3.2 Connectivity has a significant positive effect on GDP per capital

	GDP per capita (log)	Employment
Direct connectivity 150km (log)	0.047* (0.021)	0.158*** (0.022)
Adjusted R2	0.988	0.998
Within R2	0.530	0.331
F-test 1st-stage	7,396	45,732
N	18,538	15,980
Note: *p<0.05; **p<0.01; ***p<0.001. All models contain country and year Fixed Effects and are weighted by population. Standard errors are clustered by NUTS 2.		

Source: SEO Amsterdam Economics

Various model specifications and robustness checks

Number of passengers

The results of additional model specifications are given in Table C.5 for GDP per capita and in 0 for employment in Appendix C. These additional specifications show that not only direct connectivity has a positive impact on employment, but that the number of passengers also have a positive effect. A 10% increase in the number of passengers is associated with a 0.62% increase in employment.[15]

The effect of passengers on GDP per capita is less clear cut than that of direct connectivity. A reason might be that passenger volumes represent the demand side in the aviation sector, while direct connectivity represents the supply side. The academic literature suggests that there is a strong bidirectional causality of GDP and the number of passengers. This causality is stronger from passengers to GDP than from GDP to passengers (Marazzo et al., 2010; Van de Vijver, 2014; Hakim & Merkert, 2016 and Fernandes & Pacheco, 2010). For connectivity the causal direction rather goes from the number of flights to GDP (Allroggen & Malina, 2014; Brida et al., 2016). Furthermore, higher tourism activity, resulting in increased passenger numbers, prompts travelers from northwestern Europe to allocate more spending on goods and services within southern European regions rather than within their own local economy.

Endogeneity

The additional estimations in Table C.5Table C.5 for GDP per capita and in 0 for employment in Appendix C show furthermore that the effect size of the 2SLS, hence whilst accounting for endogeneity bias, is about half compared with the same model specification using the OLS model. This finding underlines the importance of correcting for endogeneity. It is important to stress that this is an overall effect, there may be differences in effect size on the regional level.

In the base specifications, the third lag of direct connectivity was used as an instrumental variable to address endogeneity. The results of the F-test in the first stage regression indicate that the instrument is valid. The F-statistic is high (7,396), indicating that there is a strong relationship between the instrument and the endogenous variable

15 These findings are in line with recent literature (Brueckner, 2003; Green, 2007; Percoco, 2010).

in the first stage regression (log of direct connectivity in 150km radius). An instrument generally is considered as strong if the F-statistic is higher than 10 (Stock, Wright, & Yogo, 2012).

Various robustness checks indicate that the effects are rather sensitive to instrument specification (i.e. number of lags) and endogenous variable choice (passengers versus connectivity). Earlier articles (see Brueckner, 2003) seem to have exhibited similar instrument sensitivity. Our robustness checks demonstrate that a 150kmradius and third lag instrumental variables yield the most stable result as discussed in further detail in Appendix C.

Other airport connectivity measures

Airport connectivity measures are closely related. Direct, indirect and airport connectivity are highly correlated between airports and even more so on a regional NUTS3 level since airport connectivity is pooled. High correlations make identifying variations in effect size difficult since minor variations in data are attributed large explanatory power. Accordingly, it is not possible to identify statistically different effects on GDP and employment from direct, indirect or airport connectivity.

Regressions of airport connectivity and hub connectivity indicate that hub connectivity might not have an effect on GDP per capita beyond airport connectivity itself, see Table C.5Table C.5 in Appendix C. There are several reasons why hub connectivity does not exert an additional effect beyond the airports primary function. Firstly, hub connectivity is believed to decrease generalize travel cost of all air passengers in terms of price, frequency, reliability and number of offered direct destinations. As these attributes are already measured within direct and airport connectivity, identifying variation of hub connectivity only relates to the transfer passengers themselves which do not directly engage at substantial economic activity at the transfer hub. Secondly, hub airports are often located in larger cities with diverse economies, where the aviation sector may not be the primary driver of GDP growth. Thirdly, direct connectivity may have stronger multiplier effects on local businesses, tourism, and trade compared to hub connectivity. This is because direct flights facilitate easier access to markets, tourism destinations, and business opportunities, leading to more immediate and tangible economic benefits. Moreover, airports with high direct connectivity may attract more local investment and development, leading to greater economic spillovers and synergies with other sectors of the economy.

Airport size categories

Airports size categories (see Figure B.1 in Appendix B) are not statistically different in their estimated economic impact. High correlations between airport sizes, a similar issue as with connectivity types, make identifying differences in the effect tricky. This differs from Pot and Koster (2022) that find a stronger relationship for larger airports than for medium-sized and small airports based on another methodological approach and temporal-spatial setting.

Cargo flights

An estimation for cargo flights in 150km radius on GDP per capita does not provide statistically significant results (see 0). This model includes fewer observations than our base model as NUTS regions that are not close to airports that operate cargo flights are removed from the analysis. There is a positive correlation between cargo flights and GDP per capita. This result underlines the importance of cargo operations in driving economic activity, as seen in hubs like Liege and Leipzig. However, in this model specification direct connectivity is not significant. This might happen due to a selection effect or collinearity between cargo flights and connectivity. Furthermore, previous research shows that the relationship is from GDP to cargo rather than from cargo to GDP as economic growth is driving the demand for cargo (Hakim & Merkert, 2016).

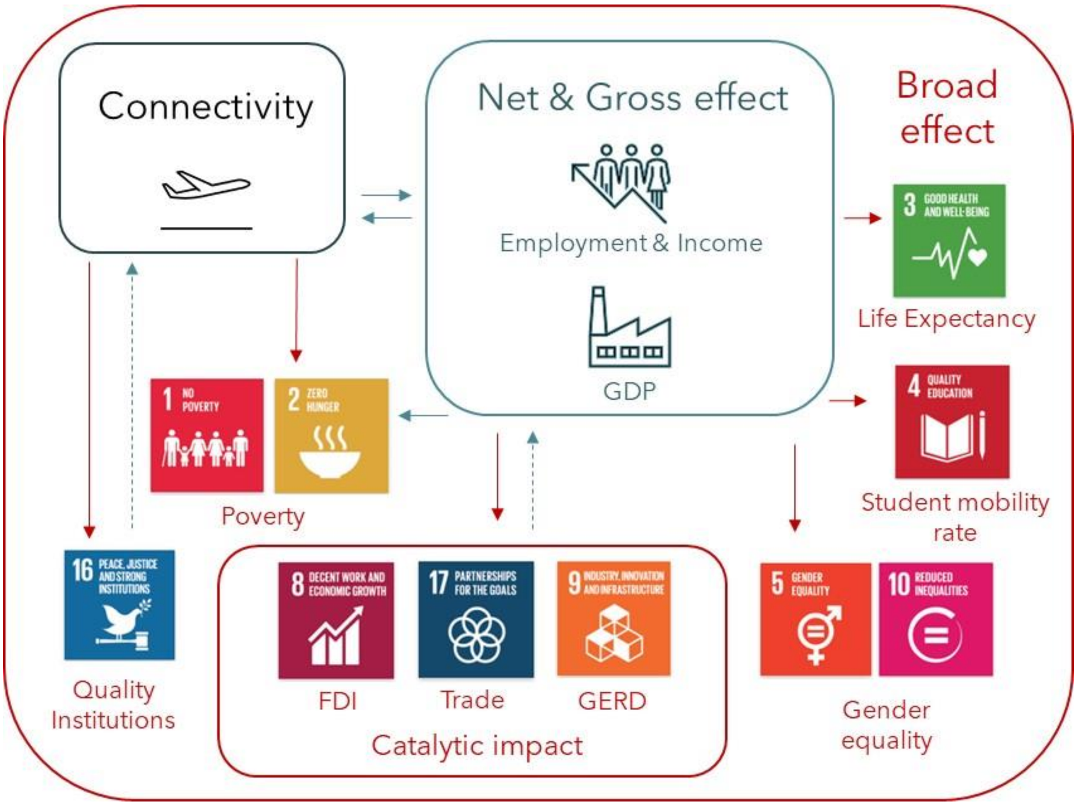
4 Broad socio-economic impact

This chapter relates air connectivity to various Sustainable Development Goals to explore airports' broader societal impact. The findings suggest the relationship is mainly indirect and is mediated through the level of economic activity (GDP). This chapter furthermore explores the environmental impact of airports' activities in 2019 in terms of climate change, air pollution and noise.

4.1 Societal impact

The analysis of the societal impacts is based on a mixed methods approach combining desk and quantitative research. The analysis takes the Sustainable Development Goals (SDG) as a natural starting point. Figure 4.1 shows the SDGs considered as relevant for aviation and airports. Potential causal mechanisms are identified using the latest academic insights. Linear regression models are estimated to make a first attempt at distinguishing correlation from causal effects between connectivity and socioeconomic variables. Data on a wide range of SDGs exist. Data are collected on country level for variables related to the SDGs (see Appendix D). To ensure coherence with the time frame employed for estimating the net impact, data from 2004 to 2019 are utilized as much as is possible in accordance with data availability.

Figure 4.1 Relationships between connectivity and socio-economic variables.



Source: SEO Amsterdam Economics

No poverty and zero hunger

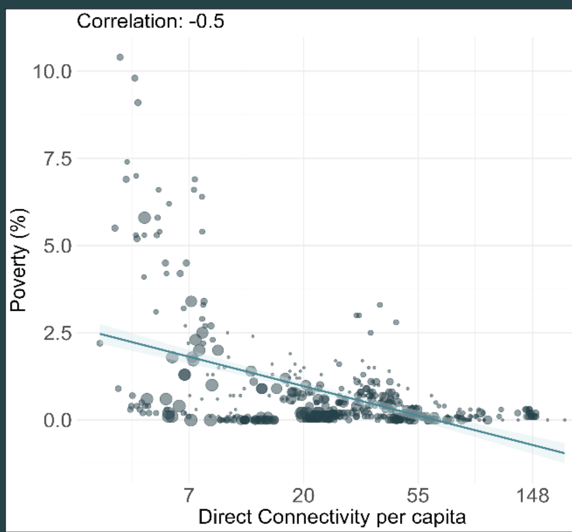
As air connectivity increases poverty decreases (see Table 4.1). Poverty is measured as the percentage of population that lives below the poverty line ($2.15 or less per day). This implies that as air connectivity increases, poverty tends to decrease, and vice versa.

Two linear models are estimated to explore the causal relationship between direct connectivity and poverty. There is a negative correlation between connectivity and poverty. A 10% increase in direct connectivity is associated with a 13.8% decrease in the percentage of population living in poverty as depicted in the first column of Table 4.1.[16] This effect is slightly weaker if GDP per capita and a time trend are added to the model to account for economic development and time effects. The remaining effect of GDP suggests that omitted variable bias such as quality of institutions and functional form could merit follow-up investigation. The effect of GDP on poverty implies that part of the effect of connectivity on poverty is mediated through GDP and time trends. This means that connectivity indirectly affects poverty through its influence on GDP and poverty has decreased over time.

Table 4.1 Connectivity reduces poverty through GDP

Poverty	OLS	OLS
Direct connectivity per capita† (log)	-1.379*** (0.143)	-0.967*** (0.179)
GDP per capita (log)	Not included	-1.471*** (0.250)
Country fixed effects	33 countries	33 countries
Time trend	Not included	0.039*** (0.009)
Intercept	2.974*** (0.333)	-63.526*** (16.099)
Observations	499	499
Adjusted R^2 (%)	0.843	0.854
Note:	†Direct weekly outbound connectivity per 100,000 inhabitants, both aggregated on country level; *p<0.05; **p<0.01; ***p<0.001 and standard errors are shown in brackets; Included countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, United Kingdom.	

Poverty and Connectivity



Source: SEO Amsterdam Economics

The effect through GDP can be explained by the relationship between connectivity and GDP. From the previous chapter we concluded that a higher level of connectivity is associated with a higher GDP. Numerous research studies have shown that economic growth reduces poverty (Adams, 2003; Baldwin, 2008; Ravallion & Chen, 1997). The studies show that higher GDP usually has a positive effect on the standard of living. This is because a larger economy

16 The table depicts the point estimate (coefficient) for each variable of interest, e.g. -1.379 for the coefficient of direct connectivity per capita on , the accompanying standard errors are given in brackets.

often means more income, better access to goods and services, improved infrastructure, and higher employment rates. These factors collectively contribute to an enhanced standard of living and, consequently, a reduction in poverty levels. It should be noted that there is no established direct relationship between air connectivity and poverty in previous literature.

Good health and well-being

The link between well-being and air connectivity is multifaceted. There is a positive correlation (53%) between connectivity and life satisfaction (see Table 4.2). Life satisfaction is measured as the self-assessed overall life satisfaction of persons on a scale from 0 to 10 (being the highest satisfaction). This implies that as connectivity increases, overall life satisfaction tends to increase.

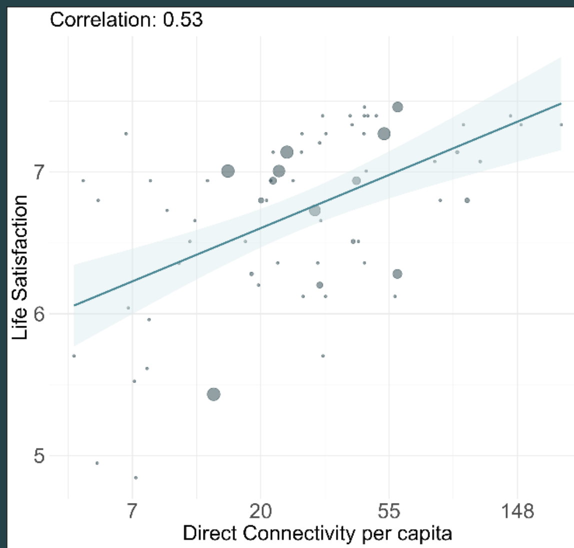
Results from the linear regression model in Table 4.2 show that a 10% increase in direct connectivity is associated with a 1.2% increase in life satisfaction. Although this effect becomes less statistically significant when controlling for GDP and a time trend, it remains positive. With data available for only two years (2013 and 2018), the model includes only 67 observations, possibly limiting statistical power, especially with country fixed effects included.

It is plausible to expect that connectivity not only directly impacts life satisfaction but also indirectly through its positive effect on GDP. Extensive research on the impact of economic growth on happiness and overall life satisfaction supports this notion, with previous studies finding a positive association (Frank & Enkawa, 2009; Mikucka, Sarracino, & Dubrow, 2017; Veenhoven & Vergunst, 2014).

Table 4.2 Connectivity and life expectancy are positively correlated

Life satisfaction (log)	OLS	OLS
Direct connectivity per capita † (log)	0.123*** (0.023)	0.057 (0.047)
GDP per capita (log)	Not included	0.052 (0.069)
Country fixed effects	Yes (34 countries)	Yes (34 countries)
Time trend	Not included	0.003 (0.003)
Intercept	1.456*** (0.055)	-4.777 (5.613)
Observations	67	67
Adjusted R^2 (%)	0.935	0.937

Life satisfaction and Connectivity



Note: †Direct weekly outbound connectivity per 100,000 inhabitants, both aggregated on country level; *p<0.05; **p<0.01; ***p<0.001 and standard errors are shown in brackets; Included countries: Albania, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, United Kingdom.

Source: SEO Amsterdam Economics

Quality of education

Air connectivity and the student mobility rate are positively correlated (41%). The student mobility rate is defined as the number of students from abroad studying in a given country, expressed as percentage of total tertiary enrolment in that country. This implies that as air connectivity increases, the share of inbound students in a country tends to be higher.

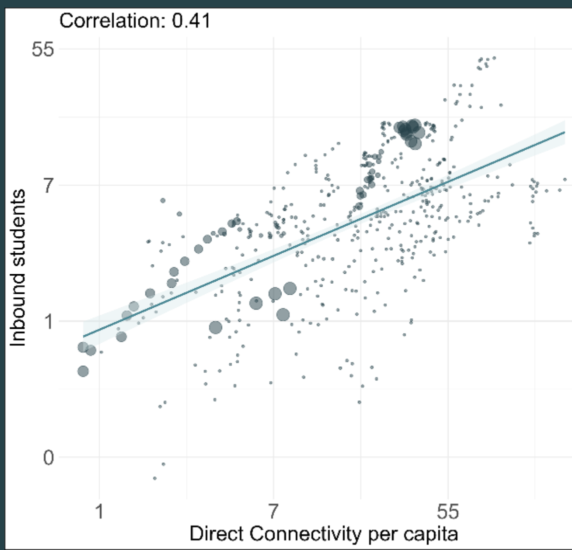
A rise in direct connectivity is associated with an increase in the share of inbound students in a country. However, Table 4.3 suggests that direct connectivity alone does not directly lead to a higher share of inbound students. Instead, its impact seems to be indirectly through GDP.

Increased connectivity drives economic growth, which boosts GDP. This fosters globalization, collaboration, and enhances the quality of education. As GDP rises, countries can invest more in education, infrastructure, and research, making them more attractive to inbound students (González, Mesanza, & Mariel, 2010; Hao, 2012). Additionally, a stronger economy provides more funding for scholarships and financial aid, creating more opportunities for international students. Overall, the indirect effect of connectivity on inbound student numbers through GDP is driven by improved educational opportunities and a more favorable environment for learning innovation and employment. Previous literature does not definitively show a direct relationship between air connectivity and the student mobility rate.

Table 4.3 Connectivity increases the share of inbound students through GDP

Inbound students (log)	OLS	OLS
Direct connectivity per capita† (log)	0.902*** (0.107)	-0.148 (0.121)
GDP per capita (log)	Not included	1.090*** (0.165)
Country fixed effects	32 countries	32 countries
Time trend	Not included	0.030*** (0.006)
Intercept	-1.476*** (0.279)	-68.399*** (11.337)
Observations	446	446
Adjusted R^2 (%)	0.797	0.979
Note:	†Direct weekly outbound connectivity per 100,000 inhabitants, both aggregated on country level; *p<0.05; **p<0.01; ***p<0.001 and standard errors are shown in brackets; Countries included: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, United Kingdom.	

Inbound students and Connectivity



Source: SEO Amsterdam Economics

Gender equality and reduced inequalities

There is a positive relationship between direct connectivity and gender equalities in employment (see Table 4.4). Gender equalities in employment are here defined as 100 minus the difference between the share of working man and women. This means that higher connectivity is correlated with higher equality in the gender gap and therefore reduced disparities in employment.

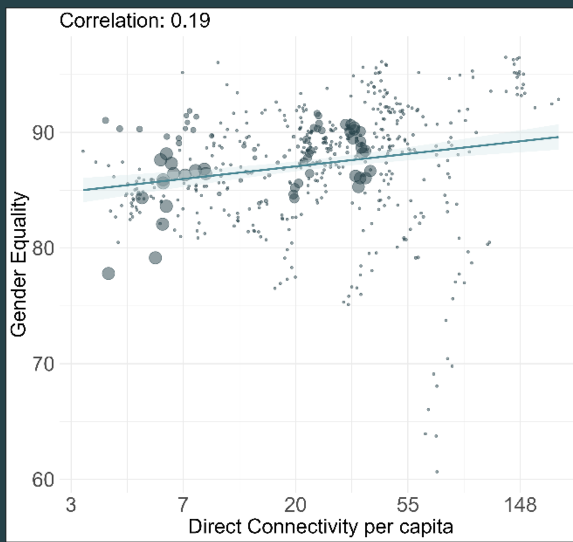
A 10% increase in connectivity increases gender equality in employment by 18.9%. However, when including GDP and a time trend into the analysis, the effect of connectivity becomes statistically insignificant. Higher GDP is negatively related with gender equality but those results might be spurious (see also the negative intercept). The positive time trend suggests that gender equalities in employment improve over time.

Several studies exist on the determinants of the gender gap in employment (Dilli, Rijpma, & Carmichael, 2014; Falk & Hermle, 2018; Witteman, et al., 2021). These studies show that persistent institutions, such as religion, legal traditions, and family practices, play a significant role in shaping gender equality outcomes. Since our model lacks variables representing these historical determinants, there may be limitations in deriving comprehensive insights solely from air connectivity and GDP. Further research is needed that incorporates a broader range of explanatory variables.

Table 4.4 The positive effect of connectivity on gender equality gets absorbed by the effect through GDP

Gender equality	OLS	OLS
Direct connectivity per capita [†] (log)	1.887*** (0.545)	-0.426 (0.577)
GDP per capita (log)	Not included	-7.062*** (0.803)
Country fixed effects	34 countries	34 countries
Time trend	Not included	0.535*** (0.029)
Intercept	81.432*** (1.209)	-934.513*** (54.760)
Observations	538	538
Adjusted R^2 (%)	0.747	0.851

Scatterplot gender equality and Connectivity



Note: [†]Direct weekly outbound connectivity per 100,000 inhabitants, both aggregated on country level; *p<0.05; **p<0.01; ***p<0.001 and standard errors are shown in brackets; Countries included: Albania, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, United Kingdom.

Source: SEO Amsterdam Economics

Industry, innovation and infrastructure

The scientific debate around agglomeration economics connects human interaction with innovation activity, research and knowledge spillovers. Aviation allows for human interaction over long distances and as such can benefit innovation. The net economic effect in the previous chapter includes part of this catalytic effect. A proxy for innovation activity is Gross Domestic Expenditure on Research & Development (GERD). Table 4.5 indicates that direct connectivity and GERD have a weak positive correlation (8%).

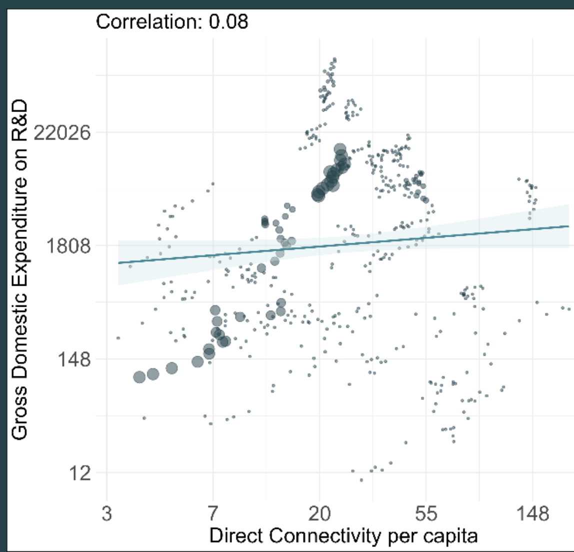
Connectivity has a positive significant effect on these Research & Development expenditures when GDP and a time trend are not included in the linear regression model. A 10% increase in connectivity leads to 8.5% increase in Research & Development expenditures. The effect of connectivity on Research & Development expenditures gets absorbed by GDP and a time trend when these are included. Connectivity might indirectly affect Research & Development expenditures through its relationship with GDP. A higher level of air connectivity fosters economic growth, leading to higher GDP levels.

Previous literature has shown that a higher GDP is associated with higher research and development efforts (Nurpeisova, et al., 2020). With increased prosperity, countries tend to allocate more resources to R&D. Additionally, the time trend component reflects changing investment patterns over time, influenced by factors such as policy changes and technological advancements. Thus, while air connectivity may not directly drive R&D expenditure, its impact on GDP can positively affect investment in research and innovation. The agglomeration benefits from air connectivity on research and innovation should affect productivity itself and not only expenditures through GDP.

Table 4.5 Connectivity has a positive effect on Research & Development through its effect on GDP

Research & Development (log)	OLS	OLS
Direct connectivity per capita † (log)	0.849*** (0.056)	-0.029 (0.041)
GDP per capita (log)	Not included	0.888*** (0.057)
Country fixed effects	32 countries	32 countries
Time trend	Not included	0.026*** (0.002)
Intercept	6.043*** (0.209)	-51.957*** (3.692)
Observations	490	490
Adjusted R^2 (%)	0.986	0.996

Research & Development and Connectivity



Note: †Direct weekly outbound connectivity per 100,000 inhabitants, both aggregated on country level; *p<0.05; **p<0.01; ***p<0.001 and standard errors are shown in brackets; Countries included: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, United Kingdom.

Source: SEO Amsterdam Economics

Peace, justice and strong institutions

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

Government effectiveness and connectivity are not usually put into direct relationship. However, Table 4.6 shows that there is a positive correlation between direct connectivity and government effectiveness (71%). This variable is defined as the perceptions of the quality of public and civil services, the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. It ranges from approximately -2.5 to 2.5.

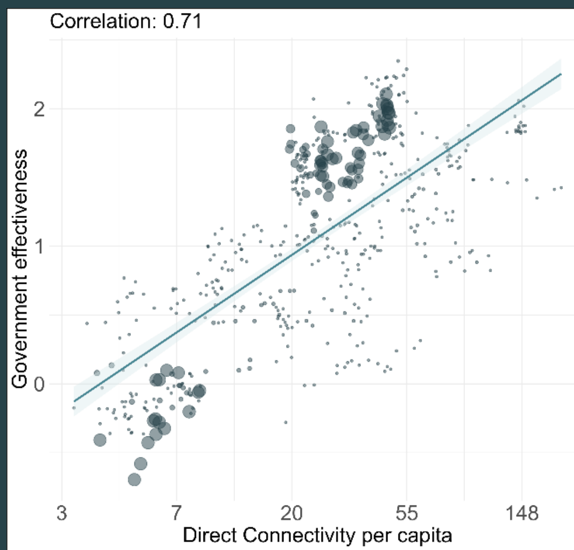
The linear models suggest that there is no significant effect of connectivity on government effectiveness. However, there is a positive effect of GDP on government effectiveness and a negative time trend. A one % increase in GDP is associated with a 0.57 unit increase in government effectiveness as shown in the second model (including the time-trend) in the table below. The negative time trend indicates that government effectiveness has worsened over time.

Previous literature provides evidence for reverse causality of economic growth and institutional quality (Chong & Calderón, 2000). Most literature has rather examined the effect of government effectiveness on GDP than vice versa and finds that there is a positive effect of government effectiveness on economic growth (Alam, Kitenge, & Bedane, 2017; De Almeida, Esperidião, & De Moura, 2024).

Table 4.6 Connectivity does not have a significant effect on government effectiveness.

Government effectiveness	OLS	OLS
Direct connectivity per capita † (log)	0.034 (0.057)	-0.060 (0.074)
GDP per capita (log)	Not included	0.570*** (0.106)
Country fixed effects	33 countries	33 countries
Time trend	Not included	-0.020*** (0.004)
Intercept	-2.648*** (0.560)	32.001*** (6.716)
Observations	497	497
Adjusted R^2 (%)	0.923	0.929

Government effectiveness and Connectivity



Note: †Direct weekly outbound connectivity per 100,000 inhabitants, both aggregated on country level; *p<0.05; **p<0.01; ***p<0.001 and standard errors are shown in brackets; Countries included: Albania, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, United Kingdom. †Direct weekly outbound connectivity per 100,000 inhabitants, both aggregated on country level.

Source: SEO Amsterdam Economics

Partnerships for UN SDG goals

17 PARTNERSHIPS FOR THE GOALS

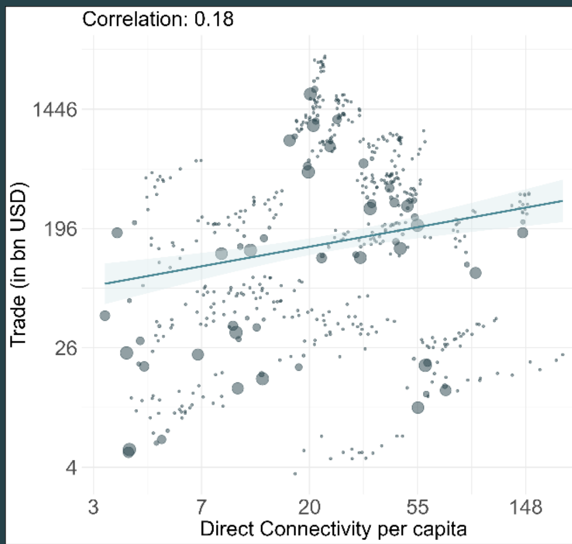
Connectivity is positively correlated with trade measured as the sum of exports and imports in USD. Enhancing non-discriminatory and equitable multilateral trading system is one of the targets within SDG 17 on Partnerships for the Goals. The naïve OLS estimations show that connectivity has a significant positive effect on trade. However, when controlling for GDP and a time trend, the direct impact of air connectivity on trade becomes non-significant. This suggests that while air connectivity initially boosts trade, its influence is mediated by broader economic and temporal factors.

This result can be explained by the following mechanism: Higher connectivity catalyzes economic growth, resulting in higher GDP levels. This facilitates greater market access, encourages globalization, and fosters the establishment of trade agreements. Businesses gain easier access to international markets, expanding their customer base worldwide. Enhanced connectivity fosters global integration by facilitating the movement of goods, services, and capital across borders, promoting trade integration among countries. Consequently, trade agreements further streamline cross-border trade, reducing barriers and encouraging more robust and equitable international commerce.

Table 4.7 Connectivity increases trade through GDP

Trade (exports +imports) (log)	OLS	OLS
Direct connectivity per capita † (log)	0.759*** (0.042)	0.004 (0.034)
GDP per capita (log)	Not included	0.976*** (0.047)
Country fixed effects	34 countries	34 countries
Time trend	Not included	0.008*** (0.002)
Intercept	21.490*** (0.093)	-1.909 (3.223)
Observations	542	542
Adjusted R^2 (%)	0.985	0.995

Trade and Connectivity



Note: †Direct weekly outbound connectivity per 100,000 inhabitants, both aggregated on country level; *p<0.05; **p<0.01; ***p<0.001 and standard errors are shown in brackets; Countries included: Albania, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, United Kingdom. †Direct weekly outbound connectivity per 100,000 inhabitants, both aggregated on country level.

Source: SEO Amsterdam Economics

4.2 Environmental impact

SDGs and aviation

Some of the SDGs have a clear focus on environmental goals, Figure 4.2 depicts these SDGs. The so-called negative externalities of aviation specifically relate to SDG's 13 (climate action), 11 (sustainable cities and communities) and 15 (life on land). This section estimates the environmental impact of European airports in terms of contribution to climate change, local air pollution and noise. [17]

Figure 4.2 Relationship of aviation and SDGs focussed on environmental goals

Source: Figure adopted from Rockström & Sukhdev (2016)

Climate change: CO_2 emissions

Aviation contributes to climate change through the emission of CO_2 and a complex set of other processes, generally referred to as non-CO_2. The CO_2 emissions from aircraft operations result from the combustion of aviation fuel. The CO_2 emissions are directly related to fuel consumption and can therefore be estimated with high accuracy. The warming effect of CO_2 is also relatively well understood. CO_2 emissions are believed to be responsible for one third (34%) of the total warming effect of aviation (Lee, et al., 2021).

To keep the global surface temperature below 1.5°C, CO_2 emissions need to be reduced to net-zero by 2050 (IPCC, 2021). The European Union is implementing more stringent climate regulation over the coming years to achieve climate neutrality by 2050. This includes a stronger reduction of the ETS cap and an increasing blending mandate for sustainable aviation fuels (SAF). On a global scale, the ICAO Member States have agreed upon a long-term aspirational goal of net-zero carbon emissions by 2050 (ICAO, 2022).

The aviation industry is committed to achieving net-zero carbon emissions by 2050. In 2021, the European aviation industry, let by ACI EUROPE, A4E, ASD, ERA and CANSO developed a joint roadmap – Destination 2050 – to reach this target (NLR and SEO Amsterdam Economics, 2021). A few months later IATA adopted a global resolution to

17 The geographical scope of the environmental impact section is consistent with the other impact sections. It covers the countries in which ACI EUROPE's airport members are located (i.e. in the European Union, the European Economic Area and a few other countries).

reach net-zero carbon emissions by 2050. The net zero target requires action from all public and private stakeholders and can only be reached through a combination of measures consisting of: (1) the development of innovative aircraft technology, (2) more efficient flight operations, (3) a larger uptake of SAF and (4) market-based measures (MBMs) such as ETS or CORSIA (ICAO, 2022; NLR and SEO Amsterdam Economics, 2021; IATA, 2021).

Climate change: Non-CO_2

The most relevant non-CO_2 processes are emissions of NO_x and the formation of contrail cirrus along the flight path (Lee et al., 2021). Currently, the climate impact of non-CO_2 cannot be assessed with the same level of accuracy as the CO_2 impacts. That is because non-CO_2 processes have different lifetimes and are time- and space dependent. The latest scientific evidence suggests that the combined warming impact of non-CO_2 processes is twice as large as the warming impact of CO_2 alone (Lee et al., 2021).[18] However, large uncertainties regarding the warming impact of non-CO_2 remain.[19]

Although climate policy is currently focused on reducing CO_2 emissions, Europe's ambition to reach climate neutrality by 2050 may result in regulation targeted at reducing non-CO_2. There are various options to reduce aviation's non-CO_2 impact, such as rerouting aircraft around ice-supersaturated areas and optimizing flight times to reduce the risk of contrail formation. However, the rerouting of aircraft may incur a fuel penalty and therefore lead to additional CO_2 emissions, which has a much longer lifetime than non-CO_2. Alternatively, more stringent engine emission standards regarding NO_x and soot may be implemented to reduce net NO_x emissions and contrail cirrus forcings. The non-CO_2 impact may also be reduced by measures focusing on CO_2 reduction. The take-up of SAF for instance reduces the risk of contrail cirrus.

Air pollution

Air pollution has a negative impact on public health, agricultural revenue, buildings and biodiversity. The health impacts seem most relevant. Pollutants for instance contribute to the development or aggravation of respiratory and cardiovascular diseases and may lead to lung cancer and premature mortality. Children, pregnant woman, elderly and people with existing health issues are especially sensitive to air pollution (European Environment Agency, 2020). The health issues have a large impact on the lives of the people involved. They also have economic consequences in terms of reduced productivity and additional medical costs.

Aircraft operations are the primary source of pollutant emissions around airports. Pollutant emissions are mainly caused by the incomplete combustion of aviation fuel. Relevant pollutants include particulate matter (PM),[20] sulphur oxides (SO_x), volatile organic compounds (VOCs) and unburnt hydrocarbons (HC), nitrogen oxides (NO_x) carbon monoxide (CO) and ground-level ozone. Of these, PM and NO_x are believed to be most harmful to human health (European Environment Agency, 2020).

Health impacts differ between airports depending on population density and concentrations of small particles and nitrogen oxides close to the ground. The concentration levels in turn depend on the number and type of aircraft movements, as well as wind direction and speed, season, time of day and terrain. Pollutant concentrations from airport sources are highest close to the airport but decrease when moving away from the airport's perimeter. Pollutant emissions are regulated through:

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18 This means that the total warming impact of aviation is around three times the warming impact of CO_2 alone.

19 The uncertainties regarding the warming impact of non-CO_2 are 8 times larger than those of CO_2 (EASA, 2023).

20 PM may also result from brake, tire and runway wear.

- **Source-specific emission standards:** The ICAO Committee on Aviation Environmental Protection (CAEP) and its predecessors have since the late 1970s addressed the need for emission standards for aircraft engines. CAEP developed emission standards for CO, HC, NO_x, soot and nvPM which are part of the certification process of the engines (ICAO, 2020).[21] The standards are gradually tightened. Modern engines for subsonic aircraft generally tend to easily achieve the CO and HC emission regulations. These pollutants are now of such low concentrations that they are no longer considered to be much of a concern in urban areas and around airports (Owen et al., 2022);
- **Air quality standards:** The EU Ambient Air Quality Directive (2008/50/EC) sets limits for PM[22], NO_2, O_3 and sulphur dioxide (SO_2) concentrations in ambient air. Member States are required to implement measures to improve air quality if limit values are exceeded and to maintain these standards when air quality is good (European Environment Agency, 2020). Furthermore, the European Green Deal's Zero Pollution Action Plan aims to reduce pollution to levels that are no longer harmful to public health and natural ecosystems by 2050. A key intermediate target for 2030 is to improve air quality to such an extent that the number of premature deaths caused by air pollution reduces by 55% compared to 2017 levels (EASA, 2023).

In addition, airports have introduced emission dependent landing fees to incentivize airlines to use the best available engine technology (Schaefer, 2006). As mentioned above, SAF has a lower sulphur and aromatic content than conventional aviation fuel. The uptake of SAF shall therefore contribute to a reduction in PM and SO_x emissions.

Noise

Noise affects communities and natural environments around airports. The negative impacts consist of annoyance, health impacts, productivity losses, disturbance of quiet areas, environmental impacts and land use restrictions (European Environment Agency, 2020; CE Delft, 2023). Noise impacts differ between airports depending on the number of people residing near the airports and the noise levels they are exposed to. These depend on a range of local factors including traffic volume, fleet mix, population density, air traffic management, runway layout, airport opening hours etc.

The Environmental Noise Directive (END) (2002/49/EC) and the Balanced Approach Regulation are the EU legislation under which environmental noise is monitored, communicated to the public and actions subsequently taken by Member States to reduce noise exposure in cities and near major transport infrastructure. The EU Zero Pollution Action Plan aims to reduce the share of people chronically disturbed by transport noise by 30% in 2030 compared to 2017 levels (EASA, 2023).

European airports have also implemented measures to reduce aircraft noise. A recent survey by ACI EUROPE indicated that 79% have some sort of noise restrictions in place, e.g. restrictions on noisy aircraft, night flight restrictions, runway restrictions, noise quota and movement caps. Furthermore, airports may differentiate landing charges based on the noisiness of the aircraft.

EASA expects that – despite increases in air traffic and population - noise around airports will reduce over the coming decades with the penetration of next-gen aircraft such as the Boeing 737MAX and Airbus A320neo, which account for most traffic movements. Noise exposure can also be reduced through changes in air traffic management and land-use planning.

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21 Annex 16 Volume II of the Chicago convention defines certification standards.

22 EU air quality limits exist for PM_{10} and $PM_{2.5}$, but not for ultrafine particles ($PM_{0.1}$).

Methodology

The environmental impacts in terms of climate change, air pollution and noise were estimated for each flight and summed up at the airport level. This section describes the methodology used. For a more elaborate description of the methodology, we refer to Appendix D.2.

Climate change

CO_2 emissions were modelled for each flight in 2019. Only departing flights were considered to prevent double counting. CO_2 emissions are directly related to fuel consumption. First, the fuel consumption for each flight was calculated based on the flight distance and aircraft type used. Second, fuel consumption was converted to CO_2 emissions by using emission factors of 3.15 for jet and turboprop aircraft and 3.10 for piston aircraft.

The non-CO_2 impacts were derived from the CO_2 emissions. Based on the latest scientific evidence it was assumed that the non-CO_2 impacts – in terms of CO_2 equivalent units or CO_2e – are twice as large as the CO_2 impacts (Lee et al., 2021).

Air pollution

Pollutant emissions were modelled with the FLAPS.25 model for each Landing/Take-off (LTO) cycle in 2019. FLAPS.25 is a state-of-the-art model specifically designed to estimate local airport emissions, see Box 4.1. It follows a bottom-up approach whereby the various types of pollutants are estimated separately for each phase of the LTO-cycle: approach, landing, taxi-in, taxi-out, take-off and climbout.[23] The reason for this is that fuel consumption and emissions per kg of fuel consumption differ between the various flight phases. FLAPS.25 separately estimates pollutant emissions from Auxiliary Power Units (APUs) to provide a complete overview of aircraft-related emissions. For this study the most relevant pollutant emissions are modelled: PM[24], SO_x, VOC, HC, NO_x and CO.

Noise

Noise impacts around airports are dependent on multiple airport-specific factors, such as traffic volume, fleet mix, population density, air traffic management, runway layout, airport opening hours etc. (see above). Conducting a detailed noise assessment for each ACI EUROPE airport based on these factors was beyond the scope of this project. Instead, the noise impacts for each airport are estimated based on available data.

Box 4.1 FLAPS.25 can be used for different purposes

Airports can use the FLAPS.25 model various purposes, such as estimating current or future pollutant emissions, benchmarking emissions against peers, monitoring emission trends to keep track of emission targets or to estimate the impacts of fleet renewal or operational changes. FLAPS.25 is highly flexible and therefore suitable for any airport. The model can provide an accurate assessment of pollutant emissions based on actual flight movements, aircraft and engine types used and operational procedures (such as duration of flight phases, thrust settings, taxi operations and APU use). When specific data is not available the model reverts to airport or industry average.

23 Pollutants mix with ambient air up to an altitude of 3,000ft. Above this altitude hardly any mixing takes place. Also, emissions close to ground level are most relevant as that is where inhalation occurs. The 3,000ft boundary is also used for engine certification purposes and for reporting of national emissions under the EU National Emissions Ceiling Directive. It also corresponds to the flight phases that make up the LTO-cycle.

24 For the aircraft's main engines, a distinction could be made between non-volatile PM (nvPM) and volatile PM (vPM) emissions. For the aircraft's APU the data only allowed for an estimation of nvPM.

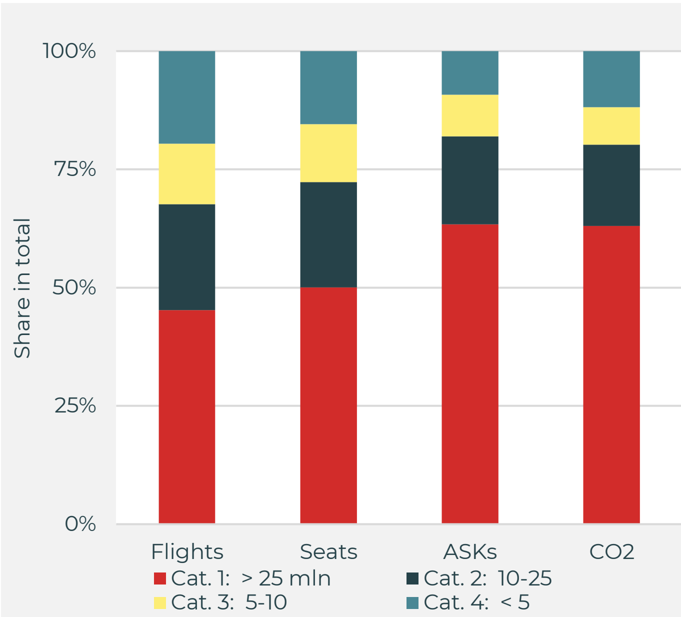
Impact estimation

Climate change: CO_2 emissions

Flights departing from European origins emitted an estimated 211 Mt of CO_2 in 2019. CO_2 emissions differ significantly between airports depending on flight activity and average flight distance. Emissions are naturally related to number of flight operations and especially the type of aircraft used for the flight and its specific fuel consumption.

The largest share of the total aircraft CO_2 emissions, 63%, occurs at the largest category 1 airports - with more than 25 million passengers per year, see Figure 4.3. This share nearly equals the share of these airports in total available seat kilometers provided. Hence, the relatively high share of CO_2 emissions at large airport is explained by the fact that large airports have a higher share of medium- and long-haul flights, which contribute more to CO_2 emissions.

Figure 4.3 Flights, seats, ASKs and CO_2 by airport category



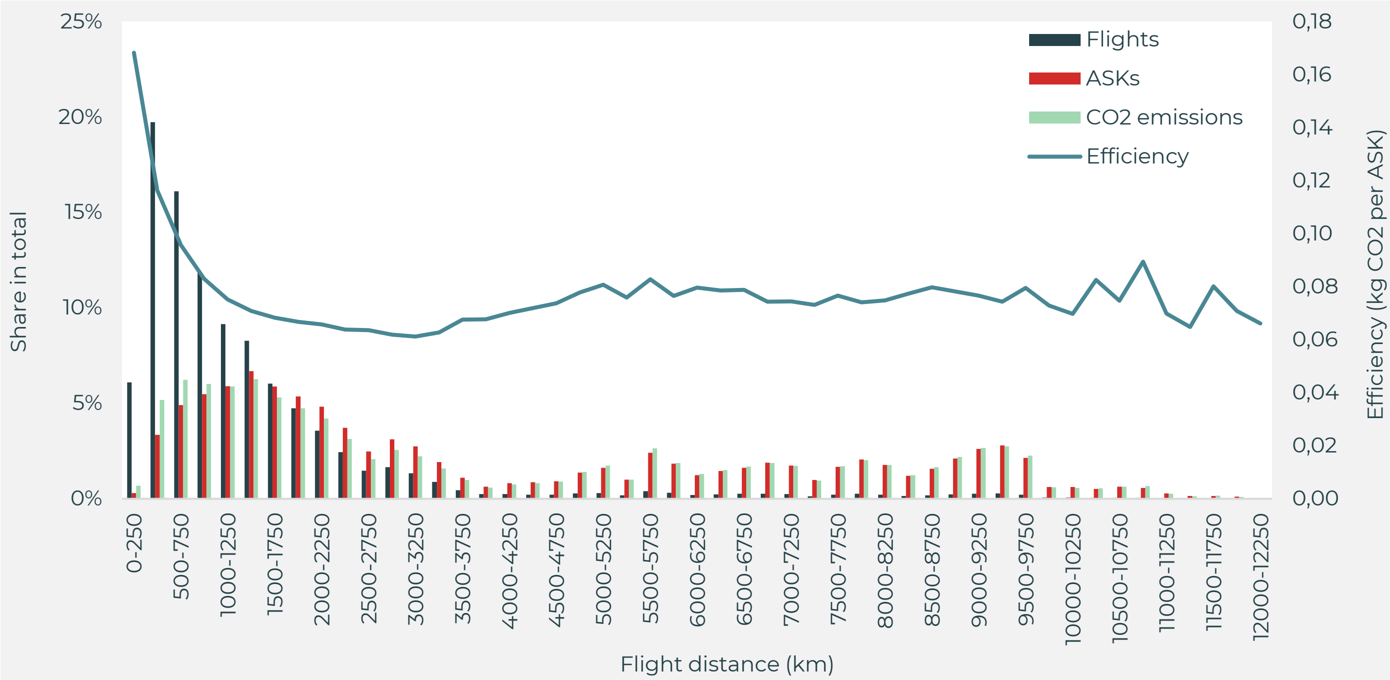
Source: FLAPS.25 model

The relatively high share of CO_2 emissions among category 1 airports is also partly due to a slightly lower fuel (and therefore CO_2) efficiency compared to smaller airports. Most large airports are hub airports which are characterized by a combination of (very) short feeder flights and long-haul intercontinental flights. These types of flights appear least fuel efficient (see Figure 4.4). Also, network carriers generally operate a somewhat older fleet than low-cost carriers, which mainly operate from medium-sized and smaller airports.

Climate change: Non-CO_2

The non- CO_2 impacts of European aviation is estimated at 422 Mt CO_2e in 2019. Larger airports have a higher share in the non-CO_2 impacts than smaller airports. This is due to the fact that large airports have a higher share of medium- and long-haul flights, which spend relatively much time at cruise altitude where the risk of contrail formation is most prevalent.

Figure 4.4 Short- and long-haul flights are less fuel-efficient than medium-haul flights



Source: FLAPS.25 model

Air pollution

The total air pollution impacts of European aviation is estimated at 1.0 kt PM, 8.3 kt SO_x, 9.1 kt VOC, 7.9 kt HC, 89.5 kt NO_x and 69.6 kt CO in 2019. Hence, in absolute levels, NO_x and CO are the most important air pollutants in aviation. European origin flights were responsible for 21-22% of aviation-related pollutant emissions in 2019 (see Table 4.8). This corresponds to the share of European aviation in global flight movements (22%). The majority of pollutants is emitted by the aircraft's main engines during landing and take-off. Emissions from the use of the APU were relatively limited. However, these may contribute significantly to pollutant concentrations at the platform.

Table 4.8 Pollutant emissions around European aviation make up 21-22% of global emissions from aviation

Pollutants (kt)	**World**			**(European) Airports in scope**			
	Main engines	*APU*	***Total***	*Main engines*	*APU*	***Total***	*Share*
PM	3.0	1.7	**4.7**	0.6	0.3	**1.0**	21%
SO_x	37	1.7	**38.6**	8	0.4	**8.3**	22%
VOC	42	1.0	**42.9**	9	0.2	**9.1**	21%
HC	36	0.8	**37.3**	8	0.2	**7.9**	21%
NO_x	404	12.7	**416.5**	87	2.9	**89.5**	21%
CO	319	12.1	**331.0**	67	2.3	**69.6**	21%

Source: FLAPS.25 model

Note: APU emissions are very dependent on APU running time. Data on average APU running times was not available for individual flights. Therefore, an average running times are used for 2- and 4-engined aircraft (ICAO, 2020).

Noise

Noise exposure data is publicly available for EU airports with more than 50,000 flight movements per year. Member States share this data with the European Environmental Agency under the Environmental Noise Directive (END). The latest available data is from 2017 and is complete for 77 airports, all of whom are ACI EUROPE members. The data shows that the local noise situation differs significantly between EU airports and does not seem to be strongly related to traffic volume. This suggest that other factors, such as the use and orientation of runways vis-à-vis population centers, are more relevant for explaining differences in noise exposure.

5 Synthesis and conclusion

Airports and air connectivity in Europe have a positive impact on the economy in terms of employment and productivity. Rendering our primary findings in an economic footprint shows that about 6% of all jobs and 5% of GDP in Europe can be associated with aviation.

5.1 Summary

Our findings

Table 5.1 summarizes data, methods and interpretation of each approach used in this study. The longitudinal data concerns the period 2004-2019. For the gross economic impact the focus is on one point in time, 2019. The approaches furthermore differ in modelling. Whilst the input-output analysis to arrive at the gross economic impact is a deterministic model, the identification and quantification of the net economic impact relies on stochastic (econometric) models. Similar stochastic models are applied to identify the broader societal impact, but with a focus on correlations instead of causal relationships between the variables of interest: number of direct flights (connectivity), GDP, employment, non-traditional indicators linked to the Sustainable Development Goals and global and local environmental externalities.

Table 5.1 Impact measurements: data, methodology and result overview

Approach	Gross Economic Impacts	Net Economic Impacts	Broader Societal Impact
Data input	Airport survey National statistics 2019	Connectivity, ACI passenger and cargo data Regional statistics (NUTS3) 2004 – 2019	National statistics and scientific literature Flight operations 2004-2019
Method	Predictive modelling Input-Output analysis Sectoral linkages Deterministic	Spatial Econometrics Stochastic (Econometrics) Causally linked variables	Mixed Methods Approach Qualitative and Quantitative Descriptive Correlations
Results	Gross economic impact Direct impact Indirect Impact Induced Impact Catalytic Impact	Net economic impact (incl. substitution/complementarities) Marginal and average impact	Non-traditional economic impact (SDGs) Positive and negative externalities Cascade of impacts
Interpretation	Point in time (2019) National impacts	Over time (panel 2004 - 2019) Regional impacts and spillovers to other regions	Over time (panel, where applicable) National impacts
Approach	**Synthesis**		
Data input	Quantitative and qualitative results		
Method	Mixed methods		
Results	Insights and overview of the three types of impacts: Gross Economic Impact, Net Economic Impact and Broader Societal Impact		

Source: SEO Amsterdam Economics

For each of the approaches, the main findings are summarised in Figure 5.1 and below:

- The gross economic impact of European airports and air connectivity in 2019 equals €505 billion and is composed of direct (€121bn), indirect (€89bn), induced (€121bn) and catalytic tourism (€174bn) impacts. The associated gross employment is 8.1 million jobs. These gross economic impacts apply to aviation of the year 2019;
- The analysis of the net economic impact shows a GDP increase of 0.5% and employment increase of 1.6% for every 10% increase in connectivity.
- Overall connectivity of European airports increased by 24% on average in the 16 years between 2004 and 2019. Given the elasticity estimate, this 24% increase in connectivity is associated with €216 bn GDP and 8.6 million jobs;[25]
- The broader societal impact in terms of the SDGs exhibits positive correlations between SDGs indicator variables and direct air connectivity. The causality between air connectivity and SDGs is through its impact on GDP and employment;
- The environmental impact analysis quantifies the levels of CO_2 emissions, non-CO_2 emissions and pollutants aggregated for European airports in 2019. Such aggregate measures are not available for noise. Flights departing from European origins emitted an estimated 211 Mt of CO_2. The non- CO_2 emissions of European aviation is estimated at 422 Mt CO_2 equivalents. Other pollutants considered include NO_x, SO_x , PM, VOC and HC.

Discussion of contextual factors

The modelling assumptions for each of the approaches have been explored and discussed in the relevant chapters, however there are a few overarching contextual factors with a potential impact on the results for which it is not possible to control for:

- Political and trade integration. The analysis period coincides with the main part of the European integration and the high point of (trade) globalization. Without these political gains, the estimated effect would be smaller or absent, see a counterexample in aviation growth in Southeast Asia without political integration where no GDP effect was measured by Hakim & Merkert (2016).
- Host of technologies. The effect we estimate for aviation occurred during a time of substantial technological and organizational development. The proliferation of information technologies stimulated decentralized work effort, specialization and optimized supply chains. As such, air transport used for productive purposes is one complimentary component in the modern economy that is necessary but alone not sufficient for the GDP effect measured. It is beyond the scope of this work to disentangle these parallel effects. For this reason, the interpretation of these figures should be those of association with aviation, as in contrast to directly causally linked to one factor.
- Validity and uncertainty. The estimation is considered internally valid for the countries these apply to and according to the sensitivity analysis. The external validity of the estimates here is supported by the effects measured by McGraw (2020) and Brueckner (2003). The uncertainty of the point estimate of the net effect as reported in Chapter 3 (Table 3.2) suggests that there are large between country differences in effect size and that true effect could be 50% lower or higher given the probabilistic nature of the estimate (i.e. the size of the standard error).

25 Since connectivity increased by 24%, this corresponds with a 3.6% employment increase which translates to 8.6 million jobs of the 227 million employees in 2019 in the fifty countries considered. Following the same line of argumentation, this 1.2% increase in GDP is €216 bn of a total €18 trillion GDP in scope.

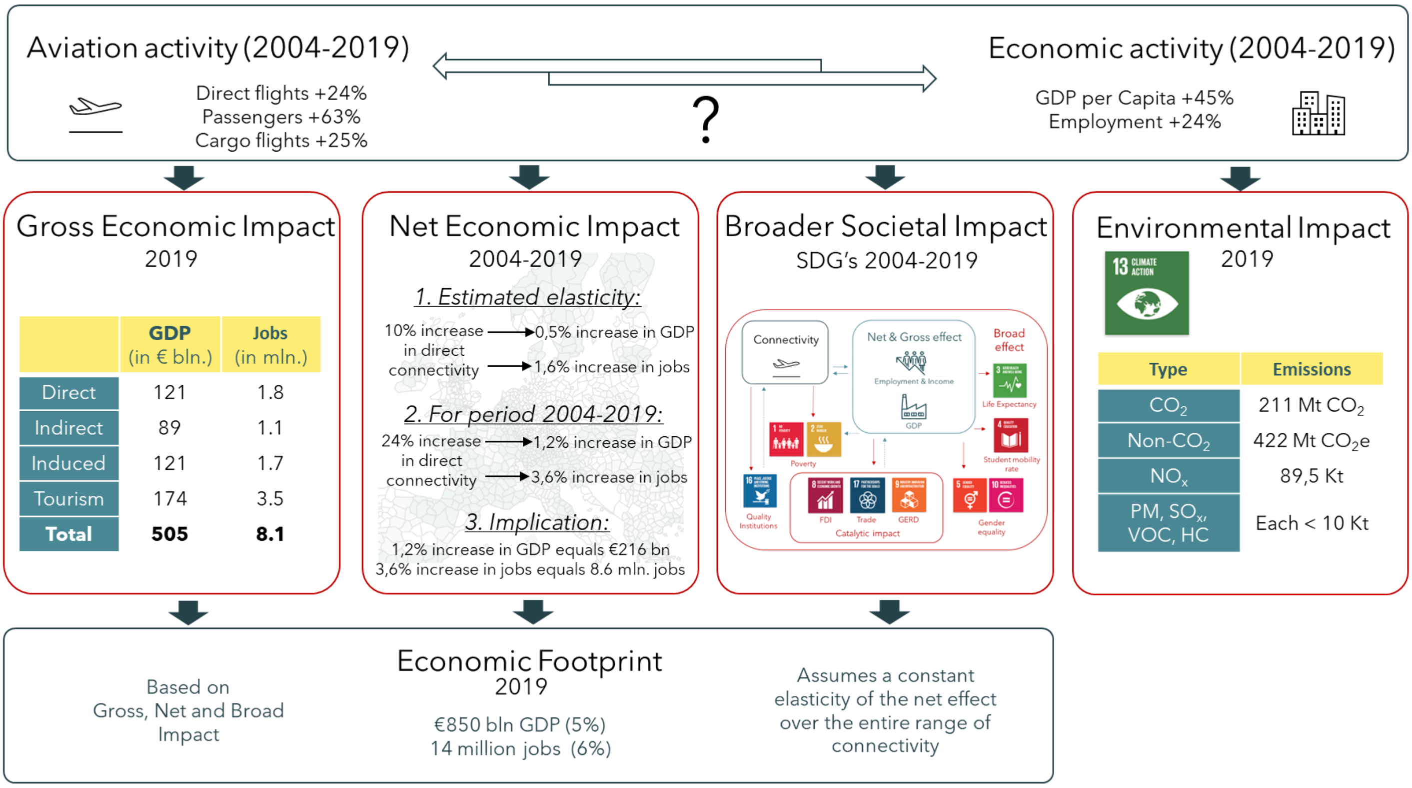
5.2 Combining results into a footprint

Footprint

The gross, net and broad impact together provide each a piece of information to arrive at the overall economic impact of airports and air connectivity. To arrive at a synthesis of the three impact measurements, one needs to combine the overlapping but distinct methodologies and outcomes. While the gross and net impact are expressed in output for GDP and the employment effect in jobs added, the broad impact also includes aspects that cannot easily be expressed in monetary terms such as quality of institutions and (gender) equality.

Here we provide a tentative quantification of the combined aggregated effect, which could be labelled as a footprint. Since not all effects are monetized, such as the environmental impacts, the footprint does not give a complete picture. Furthermore, a strong assumption is needed to use the estimated elasticities of the net economic impact modelling (a marginal analysis) to arrive at levels of economic impact. The assumption is that the average estimated elasticities of GDP and employment with Connectivity and Passengers are representative for the total impact over all levels of the variables. This requires that the returns to connectivity are not marginally decreasing over time or volume. Such constant marginal returns to input factors are hard to reconcile with economic theory. The expansion of the EEA and European integration during this time period, however, suggests that gains might be close to the average effect.

Figure 5.1 The economic and social impact of European airports in a nutshell



Source: SEO Amsterdam Economics

Our results show that for the net economic impact a point estimates of 10% connectivity growth leads to 0.5% GDP growth and 0.6% employment (from 10% pax growth) respectively. Under the stated assumption, these figures can be expanded to incorporate total effects, i.e. 100%. The total effect of 100% connectivity is then about 5% of GDP, hence approximately €850 billion, see Figure 5.1.[26] In terms of employment this relates to 6% of all employment, or about 14 million jobs.[27] The uncertainty expressed in the standard error of Table 3.2 suggest that with 90% confidence the total GDP effect is between 2.6% and 6.8%.[28]

Catalytic impact agglomeration

It is possible to compare the relative size of the gross impact and the footprint derived from the net impact. This comparison is only possible and valid under the additional assumption that underlying price, labor and capital adjustment over space have no impact on the total gross effect. Only in that case, the total gross effect is equivalent to the total net effect, otherwise the total gross effect remains unknown. In other words, one needs to assume that capital and labor used for economic activity in the aviation sector did not reduce the productivity of other sectors in the economy. Without this assumption it is not possible to determine the "true size" of the net impacts separated into gross impact categories.

Under this assumption, the total catalytic impact equals the difference between the overall net economic impact and the sum of direct, indirect and induced impact as quantified via the input-output model. Following the literature, we conjecture that the catalytic impact consists of three main effects:

- tourism effects, size known from the input-output results;
- spillover effects;
- and the broader effects related to SDGs, such as trade and impact on education and R&D.

The input-output results show that the tourism catalytic impact is about 20% of the GDP impact and 29% of employment impact, see Figure E.1 and Table E.2 in Appendix E for a direct comparison and the shares of each component. The combination of spillover effects, which include agglomeration benefits and innovation as well as benefits from market access, trade liberalization and supply chain optimization, are at total of 41% in GDP and 33% of employment (same figures and table in Appendix E), indicating the higher value creation per unit of labor. Note that the uncertainty in the point estimates (i.e. the standard errors in Table 3.2) suggest that the relative and overall size of the catalytic impact from spillovers might be significantly different in size, both in terms of cross country heterogeneity and in the aggregate.

5.3 External validity

To assess the validity of the overall results as discussed in the previous two sections in this chapter, we compare our findings with the results reported in two other but similar studies analysing the impact of aviation at the European scale and with 28 studies with airport and national scope. In the data collection phase, one of the requests in the survey was to submit any available airport specific impact studies. Following this request, 28 studies have been submitted for 12 countries. These studies cover the years 2015 to 2023. They vary in scope, with some focusing on specific airports, while others examining groups of airports or entire countries. We conclude from these studies that there is no clear alignment for some of the indicators, especially on the catalytic impact. For instance, some surveys

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26 This is 4.7% of €18 trillion of total GDP over all included regions in our analysis, see model 2 Table C.5Table C.4 in Appendix C.

27 This is 6% of 227 million jobs over all included regions in our analysis, see model 10 in 0 in Appendix C. Note that in the total employment effect calculation the point estimate from the passengers is used since it is the more conservative and likely the more representative of the long-term and also externally empirically validated. see (Brueckner, 2003).

28 The point estimate of 0.047 with a standard error of 0.021 and applying the general logic of the economic footprint suggest a range of 2.6% and 6.8% for the total associated economic activity within the 90% confidence interval range.

included the catalytic impact within the induced impact, while others considered it solely within the tourism impact category.

Alike a meta-analysis, the boxplots in Figure 5.2 provide information the main findings of the underlying 30 studies. In particular, the boxplots show the distribution of the ratios of the direct impact to the indirect, induced, catalytic and total impact of the submitted impact studies. A higher ratio indicates a greater direct impact relative to other impacts, with a ratio of one suggesting equal sizes between the direct impact and the impact being compared. In other words, for all ratios below 1, the direct impact is smaller than the other impact.

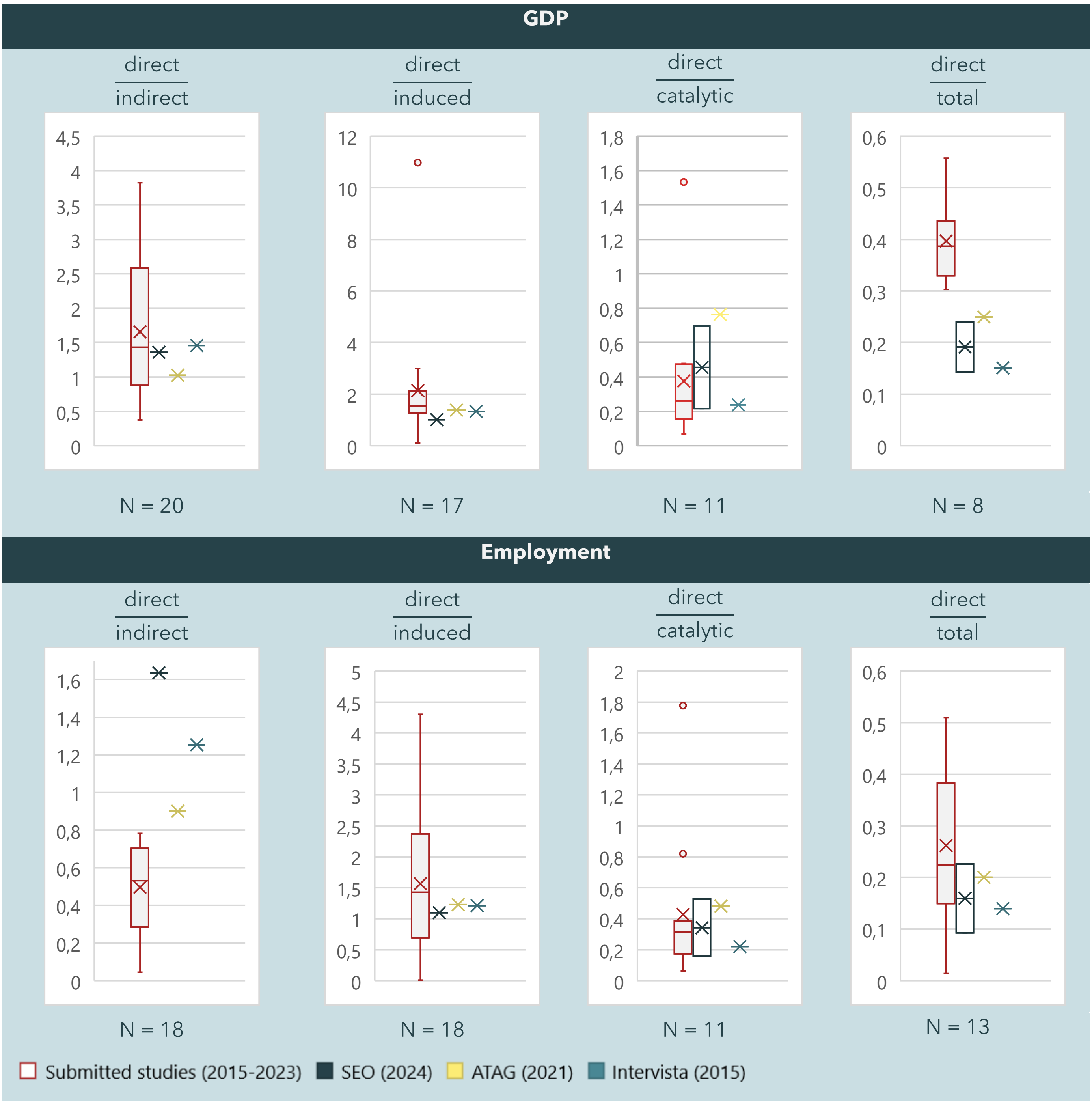
The ratios from the direct to induced impact are notably higher, indicating that the direct impacts are larger than the induced impacts in all studies. For external validity, the most interesting ratio is the one between direct impact and catalytic impact. The reason is our tentative calculation of the footprint and the agglomeration effect. The third subgraph in Figure 5.2 shows for the current study three values: the catalytic impact only based on tourism, the catalytic impact derived from the footprint including agglomeration effects and the average between the two outcomes.

The figure shows that including agglomeration effects yields a catalytic impact being five times larger than the direct impact, and if agglomeration effects are not included our approach yields a 1.5 times larger catalytic impact. In comparison with the other available studies, one observes that our estimates are within the bandwidths of the other studies.

Comparing the ratios of the current study to the other two European studies by ATAG (2021) and InterVISTAS (2015), Figure 5.2 shows that the ratios of the direct to total impact are lower for the European studies for both GDP and employment compared with the studies submitted by airports. An explanation can be that impacts that go beyond limited regional boundaries are sometimes omitted in regional and national assessments as these are less relevant to local decisions making units. Studies on a larger geographical scale take benefits to neighboring regions into account, in particular agglomeration benefits from trade and innovation.

In conclusion of the external validity, the analysis of the submitted impact studies reveals considerable variability in the ratios of direct to indirect, induced, catalytic, and total impacts across European airports. The disparities observed underscore the complex interplay of factors such as airport size, methodological approaches, and national contexts, highlighting the advantage of consistent assessment frameworks to ensure comparable evaluations of airport impacts.

Figure 5.2 The distribution of the ratios of direct impact to the other impacts differs over the underlying studies



Source: SEO Amsterdam Economics

Note: N refers to the total number of underlying studies included for the distribution plot of the specific ratio. Not all ratios are available in all studies, explaining the variation in the number of underlying observations. The boxplots summarize the distribution of data. The box represents the interquartile range, which spans from the first quartile to the third quartile. The length of the box indicates the spread of the middle 50% of the data. The line inside the box represents the median, while the cross represents the mean. Whiskers extend from the edges of the box to indicate the range of the data. Data points beyond the whiskers are considered outliers and are plotted individually. For the ratios direct to catalytic and direct to total, there is a whisker for the SEO study as the catalytic effect is once only calculated as only the tourism effect and once as the tourism plus spillover effect.

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Appendix A Overview of relevant literature

Economic impact

There is a plethora of studies that address the impacts of air travel. These studies differ in their methodology, variables, regional granularity and results. Over the years, numerous studies have explored the economic impacts of air transport. From these studies, one can distinguish three effects through which air travel enables economic impacts: the supply chain effects, the spillover effects as well as feedback effects.

Supply chain effects

National and regional assessments of the supply-chain effects are usually based on input-output models. These models depict how indirect industries utilize the output of a specific industry as inputs in the production of goods or services. They also indicate the amount of spending supported by the employees of the industry and its entire supply chain, known as the induced output (Ambargis & Mead, 2012; Barol, 1989; Batey, Madden, & Scholefield, 1993; Butler & Kiernan, 1986; Oxford Economics—SEP, 2014).

Spillover effects

The economic contribution of airports however is not limited to the aviation and supplying industries. Airports also facilitate international business through the connectivity they provide. This may translate into enhanced productivity, trade, tourism, investments et cetera. These effects are commonly referred to as spillover effects and have been examined in various studies (Britton, Cooper, & Tinsley, 2005; Oxford Economics—SEP, 2014). These studies suggest that economic interdependence is strongly influenced by accessibility via the air transport network. Consequently, air transport is seen as pivotal in mitigating geographical barriers and facilitating increased interactions. An overview over recent studies that measure the interaction between the air transport sector and the economy is provided in Table A.1 at the end of this Appendix.

Many studies found a positive relationship between air traffic growth and (regional) economic development. Earlier studies did not always address the causality issue. Does traffic growth stimulate the economic development or is traffic growth mainly the result of economic development? Or is there a bi-causal relationship? In recent years it has become more common to address the causality issue. This allows researchers not only to show the relationship between traffic and economic variables, but also indicate to what extent air traffic growth stimulates the economy.

Several studies focused on the relationship between connectivity and GDP (Allroggen & Malina, 2014; Brida, Bukstein, & Zapata-Aguirre, Dynamic relationship between air transport and economic growth in italy: A time series analysis, 2016; Pot & Koster, 2022). For example, Pot and Koster (2022) find that a 10% increase in air accessibility, measured as the number of flight opportunities, is associated with a 1.06% increase in GDP per capita in the long run. This relationship is much stronger for large airports (1.79%) than for medium-sized (0.33) and small airports (0.22).[29] Other studies examined the relationship between passengers and GDP (see Table A.1). For instance, Poort (2000) finds that a 10% increase in passenger enplanements leads to a 1.7% GDP growth.

Numerous studies have focused on spillover effects on the labor market, i.e. they have studied the effects of air transport on employment (Irwin & Kasarda, 1991; Ivy, Fik, & Malecki, 1995; Button, Lall, Stough, & Trice, 1999; Poort

29 Temporal, spatial and methodological difference mean that for directly comparing the size of point estimates across studies careful deliberation is recommendable.

J. , 2000; Brueckner, 2003; Green, 2007; Percoco, 2010; McGraw, 2020). The findings suggest that an increase in passengers is associated with higher employment (Ivy, Fik, & Malecki, 1995; Button, Lall, Stough, & Trice, 1999; Brueckner, 2003; Green, 2007; Percoco, 2010; McGraw, 2020). For example, Brueckner (2003) finds that a 10% increase in passenger numbers leads to a 1% increase in employment in service-related industries. Green (2007) finds that that a one standard deviation increase in boardings per capita is associated with an 8.0% increase in employment growth.[30] McGraw (2020) finds that higher passenger numbers, on average, lead to 3.9% growth in total employment per decade. There is some evidence for a bi-directional causal relationship of passengers and employment (Poort J. , 2000; Percoco, 2010).

Another stream of literature focuses on the effects of air cargo activity on the economy (Chang & Chang, 2009; Ali, 2023; Button & Yuan, Airfreight transport and economic development: An examination of causality, 2013; Hakim & Merkert, 2016). The studies provide evidence for a positive effect of cargo activity in GDP. Two studies find evidence for a bi-directional causal relationship between cargo and GDP (Chang & Chang, 2009; Hakim & Merkert, 2016).

Feedback effects

The dynamic relationship between air transport and the economy encompasses a range of feedback effects. In the short term, the demand for both passenger travel and freight is positively influenced by the current level of economic activity. Economic growth leads to an increase in air travel demand. Over the long term, regional economic growth yields resources for infrastructure investment, thereby triggering a cascade of stimulatory effects across various sectors of the economy, including air transport.

Measuring bi-directional causal relationships?

Numerous studies have revealed a bi-directional causal relationship between the economy and air transportation. There is few evidence that there is a bi-directional relationship between the number of flights, which serves as an indicator of the aviation industry's supply side, and GDP. Pot and Koster (2022) find evidence for a bi-directional causal relationship between flights and GDP. The relationships appear stronger for regions with large airports, which are remotely located and have a relatively large service sector. Ivy et al. (1995) however find a bi-causal relationship between connectivity and employment, whereby the causal impact of connectivity on employment is stronger than from employment on connectivity. Bel and Fageda (2008) could only prove one-way causality from intercontinental flights to the number of headquarters, whereby causality was stronger for knowledge-intensive sectors.

Literature suggest that the bi-causal relationship is more prevalent in the relationship between passengers, which represent the demand side of the aviation sector, and GDP (e.g. (Brida, et al., 2014; Baker, et al., 2015; Hu, et al., 2015; Hakim & Merkert, 2016). Hakim and Merkert (2016) find that the relationship between passengers and GDP is even stronger from the direction GDP to passengers than vice versa. Their results suggest that a 1% increase of GDP leads to a 1.2% growth in passenger numbers. Marazzo et al (2010) also find a stronger and more imminent relationship between GDP and RPKs than the other way around. Hu et al. (2015) show that a 1% increase in passengers leads to a 0.943% increase in GDP and a 1% increase in GDP translates into 1.037% more passengers. Karici and Bakir (2019) could only prove bi-causality for lower income countries; for mid- and high-income countries GDP only had a causal impact on passenger numbers. Mukkula and Tervo (2013) and Neal (2011) find a bi-causal relationship between passengers and employment. However, Neal was only able to prove these relationships in times of economic growth.

[30] Zhang and Graham (2020) translate this into an elasticity of 0.2.

Fewer studies looked at the causal relationship between air cargo and economic development. Chang and Chang (2009) found a bi-causal relationship between air cargo and GDP, whereas Button and Yuan (2013) proved bi-causality between air cargo and employment. Ali et al. (2023) only found an impact of air cargo on GDP. Hakim and Merkert (2016) on the other hand only found an impact of GDP on cargo. The same holds for Chi and Beak (2013) who established a long-term impact of income on the freight ton kilometers (FTKs).

It is important to note that the direction of causality between the aviation sector and regional economies varies depending on the level of development, as revealed by Zhang and Graham (2020) in their review of causal channels. They discovered that in less developed economies, a bi-directional causal relationship is more common. In contrast, in more developed economies, the causality tends to go only from air transport to economic growth. Particularly notable is the impact of airline enplanement on employment in service-related sectors. However, the reverse direction of this relationship is not as substantial in developed economies as previously thought in terms of causality.

The causal impact of aviation on the economy differs between airports and depends on the current network size as well as the current size and composition of the economy:

- **Current network size:** the causal impact appears larger for airports in peripheral regions than for airports in core regions (Mukkala & Tervo, 2013; Pot & Koster, 2022; Van De Vijver, 2014; Zhou, Leng, & Shi, 2022). Van de Vijver et al. (2015) for instance found a strong causal impact of aviation on the economy for peripheral regions in Malta and Estonia, but not for capital regions in the Netherlands and France. Core regions are often already well-connected and therefore benefit less from additional air connectivity. In such regions, it is mainly the economy that stimulates air traffic. Peripheral regions on the contrary are dependent on air connectivity and benefit more from the expansion of aviation networks. This is supported by Bilotkach (2015) who showed that new nonstop routes had a larger impact on the economy than frequency increases on existing routes. It also means that as air networks expand over time, their economic impacts diminish (Elburz, Nijkamp, & Pels, 2017).
- **Size of the economy:** the causal impact was also found to be larger for airports in less developed economies (Kiraci & Bakir, 2019; Van De Vijver, 2014). For developing countries, transportation infrastructure is considered a prerequisite for economic growth. For developed economies, good accessibility is relevant to maintain economic success (Skorobogatova & Kuzmina-Merlino, 2017). Aviation markets in developed economies are usually mature or even saturated (Zhang & Graham, 2020). This means that the regions in question are already well-connected. As noted above, additional connections then hardly improve accessibility. In addition, the state of the economy also appears to be important. For example, Neal (2011) found a bi-causal relationship between aviation and the economy only in times of economic growth. During recessions the link could not be established, possibly because of a lower demand for business travel;
- **Composition of the economy:** the causal impact appeared also larger for the service industry than for the manufacturing industry (Poort & Sadiraj, 2001; Pot & Koster, 2022; Van De Vijver, 2014; Zhang & Graham, 2020). This can be explained by the fact that the service industry is more dependent on face-to-face contacts with colleagues and customers, even when digital alternatives are available. According to Ivy et al. (1995), the location of production and distribution activities is mainly driven by cost considerations, such as labor costs, taxes, transport costs and land prices. Such activities are therefore found in more remote areas where costs are lower. For organizational activities - such as office functions, R&D and marketing - cost-considerations are less relevant. Such activities benefit from good access to markets, suppliers and high-skilled labor and are therefore often located in metropolitan areas with good transport and communication infrastructure. Brueckner (2003), Percoco (2010), Sheard (2014) and Lakew and Bilotkach (2018) could not establish a causal impact of aviation on employment in the manufacturing and other goods-related industries such as agriculture and construction. However, for high-tech manufacturing sectors there is evidence for a causal impact. Brugnoli et al. (2017) for

instance found a stronger causal impact of flight capacity on trade for high-tech sectors such as pharma and electronics.

Broad impact

Airports have a boarder societal and environmental impact that is arguably not fully captured by traditional economic indicators such as GDP and employment alone. There is limited literature on the direct impact of airport connectivity on socio-economic variables. However, as described above, airport connectivity has a positive impact on the economy (Allroggen & Malina, 2014; Brida, Bukstein, & Zapata-Aguirre, Dynamic relationship between air transport and economic growth in italy: A time series analysis, 2016; Pot & Koster, 2022). Connectivity exerts a broader positive influence on socio-economic variables through its contribution to GDP growth. Extensive research has explored the relationship between GDP growth and various socio-economic dimensions. For example, studies consistently show that economic growth reduces poverty (Adams, 2003; Baldwin, 2008; Ravallion & Chen, 1997). Additionally, GDP growth fosters increased investments in education, infrastructure, and research (González, Mesanza, & Mariel, 2010; Hao, 2012).

Table A.1 Literature on the relationship between air transport and the economy

Source	Air transport -> Economy	Economy -> Air transport	Country & period	Method	Journal
Connectivity <-> GDP					
Allroggen & Malina 2014)	Evident	Not evident	Germany, 1997-2006	Time-series	Journal of Transportation Management
Brida et al. (2016a)	Evident	Not evident	Italy, 1971-2012	Time-series, Granger test	International Journal of Aviation Management
SEO Amsterdam Economics (2015)	Evident [0.023]	Not evident	Europe, 2004-2011	Lagged regression	Not peer reviewed
Sheard (2019)	Evident	Not evident	US, 1991-2015	IV	Economica
Pot & Koster (2022)	Evident [0.106]	Evident	Europe, 2000–2018	Time-series, Granger test	Journal of Transport Geography
Passengers <-> GDP					
Adedoyin et al. (2020)	Evident	Not evident	US, 1981-2017	Canonical cointegration, FMOLS, DOLS	Technological Forecasting & Social Change
Akinyemi (2019)	Not evident	Evident [-1.05, +3.18]	Nigeria, 1982–2005	Time-series, Granger test	GeoJournal
Ali et al. (2013)	Evident	Not evident	BRICS countries, 1993–2019	Time-series, Granger test	Journal of Air Transport Management
Ali et al. (2023)	Evident	Evident (long-term)	BRICS, 1993-2019	Granger causality	Journal of Air Transport Management
Baker et al. (2015)	Evident	Evident	Australia, 1985-2011	Panel Granger test	Journal of Transport Geography

Balsalobre-Lorente et al. (2021)	Evident	Evident	Spain, 1970-2015	N-ARDL (lag-model), Diks and Panchenko causality test	Current Issues in Tourism
Bilotkach (2015)	Evident	Not evident	US, 1993-2009	Generalized Method of Moments (GMM)	Urban Studies
Brida et al. (2016b)	Evident	Evident	Mexico, 1995-2013	Time-series, Granger test	Transportation Planning and Technology
Brida et al. (2018)	Not evident	Evident [1.32 (Uruguay, 0.28 (Argentina)]	Uruguay / Argentina, 1970-2011	Vector Error Correction (VEC)	World Review of Intermodal Transportation Research
Fernandes & Pacheco (2010)	Not evident	Evident [1.00-2.11]	Brazil, 1966-2006	Time-series, Granger test	Transportation Planning and Technology
Hakim & Merkert (2016)	Weekly evident	Evident [1.2]	South Asia, 1973-2014	Panel Granger test	Journal of Transport Geography
Higgoda & Madurapperuma (2020)	Not evident	Evident	Sri Lanka, 1983-2019	VAR, Granger causality	Journal of Transport and Supply Chain Management
Hu et al. (2015)	Evident [0.943]	Evident (long-term) [1.04]	China, 2006-2012	Granger causality	Journal of Air Transport Management
Khanal et al. (2022)	Evident [0.158-0.382]	Not evident	Australia, 1971-2018	N-ARDL	Sustainability
Kiraci & Bakir (2019)	Evident	Evident	70 countries, 1990-2016	Bootstrap panel Granger causality, Panel causality test	Khazar Journal of Humanities and Social Sciences
Law et al. (2022)	Evident [0.19]	Evident [0.25]	CLMV countries, 1995-2018	ARDL	Journal of Air Transport Management
Marazzo et al. (2010)	Weekly evident	Evident	Brazil, 1966-2006	Time-series, Granger test	Transportation Research Part E
McGraw (2020)	Evident [0.1*]	Not evident	US, 1950-2010	Pooled synthetic control event study	Journal of Urban Economics
Mukkala & Tervo (2013)	Evident	Weekly evident	Europe, 1991-2010	Panel Granger test	Environment & Planning A
Poort, (2000)	Weekly evident [0.17]	Evident	Europe, 1992-1997	3SLS	Economisch Statistische Berichten
Passengers <-> Trade					
Van de Vijver et al. (2014)	Evident	Evident	Asia-Pacific,1980-2010	Panel Granger test	Journal of Transport Geography
Cargo <-> GDP					
Ali et al. (2013)	Evident	Not evident	BRICS countries, 1993–2019	Time-series, Granger test	Journal of Air Transport Management
Button & Yuan (2013)	Evident	Not evident	US, 1990-2009	Panel Granger test	Urban Studies

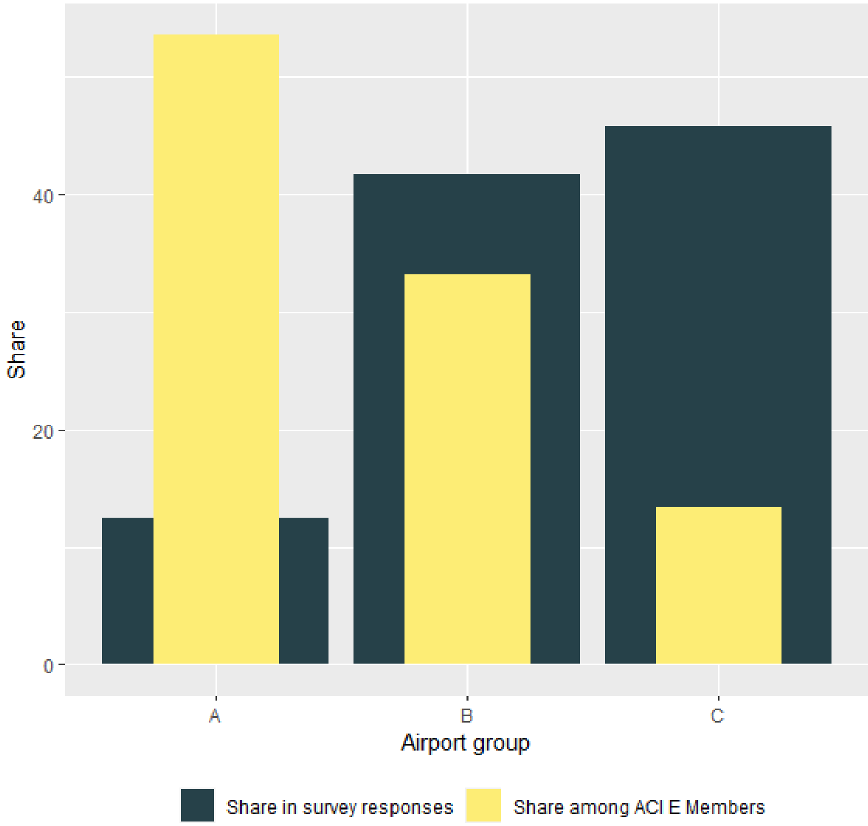
Chang & Chang (2009)	Evident	Evident	Taiwan, 1974-2001	Time-series, Granger test	Journal of Transportation Management
Chi & Beak (2013	Not evident	Evident (long-term) [7.08]	US, 1996-2011	ARDL (lag model), cointegration	Transport Policy
Hakim & Merkert (2016)	Weekly evident	Evident [0.5]	South Asia, 1973-2014	Panel Granger test	Journal of Transport Geography
Ying et al. (2008)	Evident	Not evident	OECD countries	Pedroni's cointegration test & SUR	International Journal of Transport Economics
Connectivity <-> Employment					
Cristea (2023)	Evident	Not evident	US, 1984–2013	IV (LIML)	Journal of Regional Science
Ivy et al. (1995)	Evident	Weakly evident	US, 1978-1988	IV (3SLS)	Environment and Planning A
Passengers <-> Employment					
Blonigen & Cristea (2012)	Evident	Not evident	US, 1969-1991	Quasi-Natural Policy Experiment	NBER Working Paper Series
Button et al. (1999)	Evident	Not evident	US, 1979-1997	Time-series, Granger test	Journal of Transportation Management
Brueckner (2003)	Evident [0.08]	Not evident	US, 1996	Granger test, 2SLS	Urban Studies
Green (2007)	Evident [0.2]	Not evident	US, 1990	2SLS	Real Estate Economics
Ivy, Fik, & Malecki, (1995)	Evident	Weekly evident	US, 1987-1988	3SLS	Environment and Planning A
Lakew & Bilotkach (2018)	Evident [0.047-0.063]	Not evident	US, 2004-2012	IV (2SLS)	Journal of Regional Science
McGraw (2020)	Evident [0.17*]	Not evident	US, 1950-2010	IV, caliper matching and pooled synthetic controls	Journal of Urban Economics
Neal (2011)	Evident	Weakly evident	US, 1993-2008	Lagged regression	Journal of Urban Affairs
Percoco (2010)	Evident	Weekly evident	Italy, 2002	2SLS	Urban Studies
Poort (2000)	Weekly evident [0.18]	Evident	Europe, 1992-1997	3SLS	Economisch Statistische Berichten
Sheard (2014)	Evident	Not evident	US, 2007	IV	Journal of Urban Economics
Sheard (2021)	Evident [0.04]	Not evident	US, 1991-2008	IV (2SLS)	Journal of Regional Science
Van de Vijver et al. (2015)	Evident	Not evident	Europe, 2002-2011	Granger test	Journal of Transport Geography

Note: Coefficients represent elasticities, for example, 0.18 Poort (2000) means that 1% growth in passengers results in 0.18% employment growth. * Calculated as an X% per decade growth in dependent variable divided by assumed 17% linear air traffic growth per decade.

Source: SEO Amsterdam Economics

Appendix B Gross impact

Figure B.1 In the survey response large airports are overrepresented and small airports are underrepresented



Source: Analysis SEO Amsterdam Economics based on survey among ACI EUROPE's airport members (for all figures in this Appendix)
Note: Group A, B and C contain respectively airports handling 1 – 99, 100 – 1000, more than 1000 direct flights per week.

Figure B.2 The direct impact of airports on country level GDP is an outcome of economic and population size

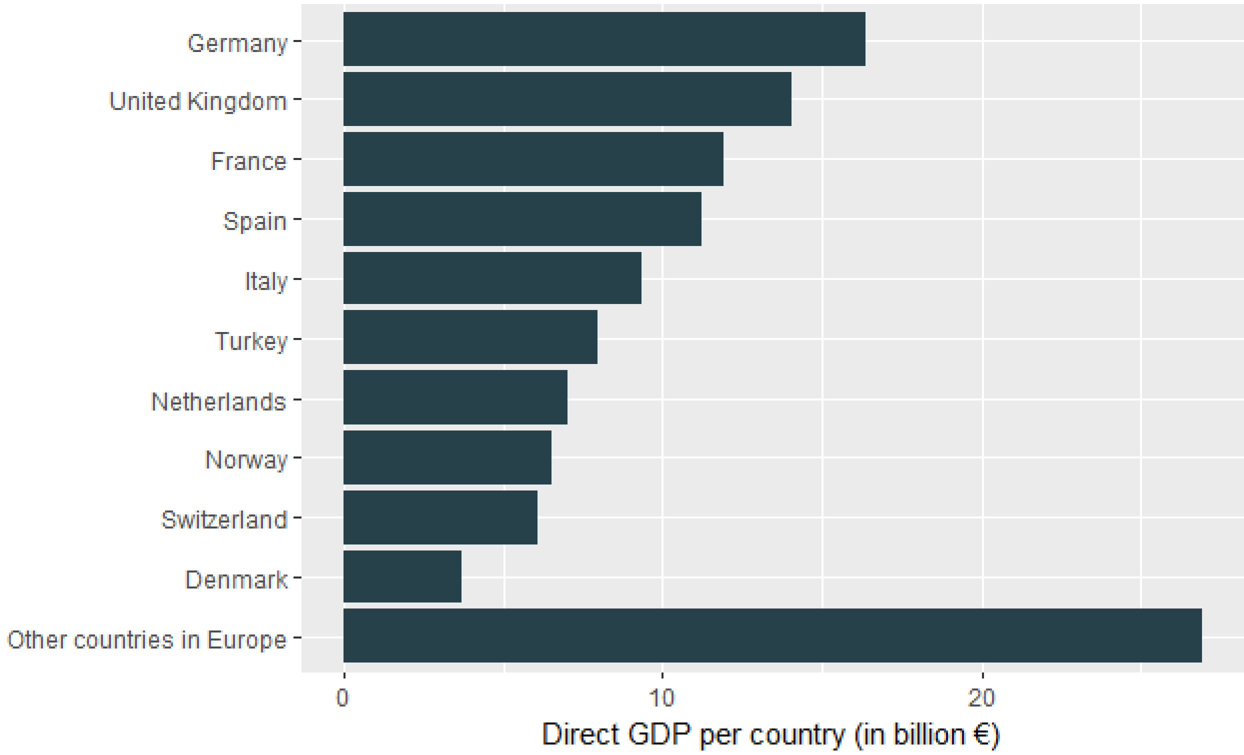


Figure B.3 The direct impact on employment is highest in Germany and the United Kingdom

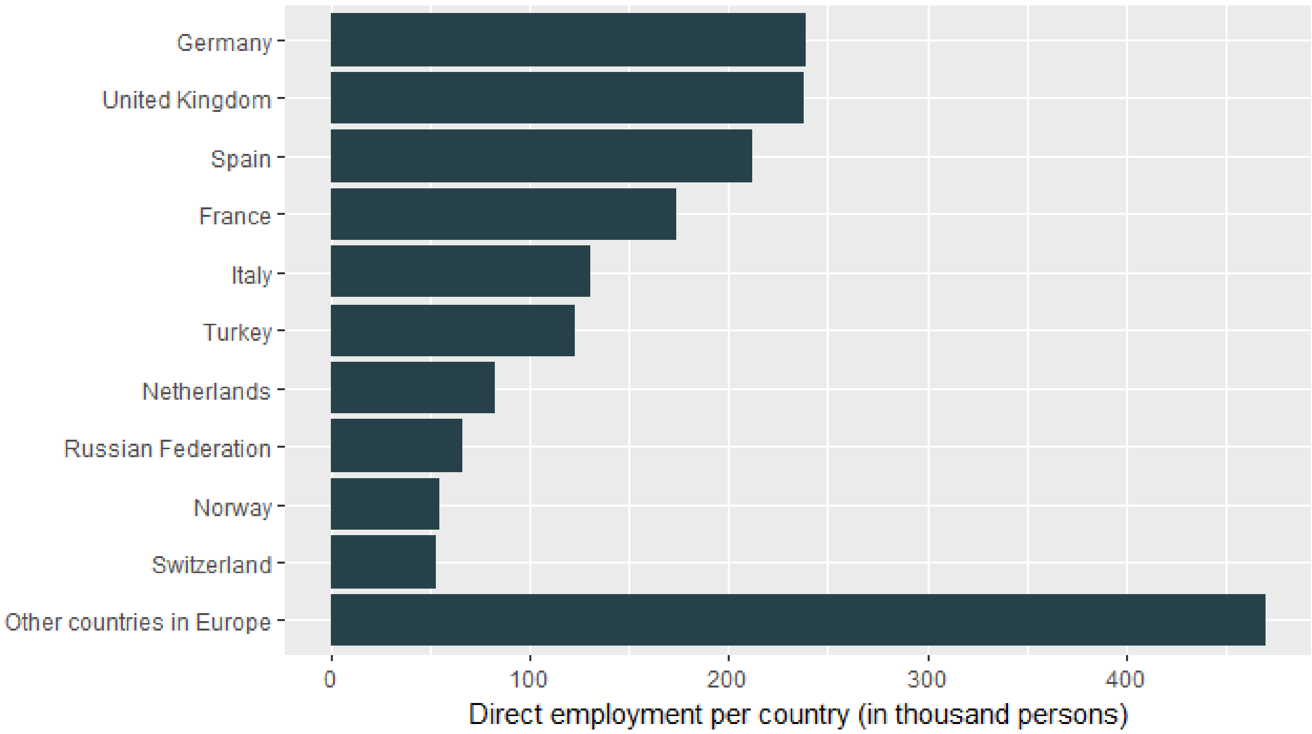


Figure B.4 The indirect impact of airports on GDP appears sorted on the countries level of aviation activity

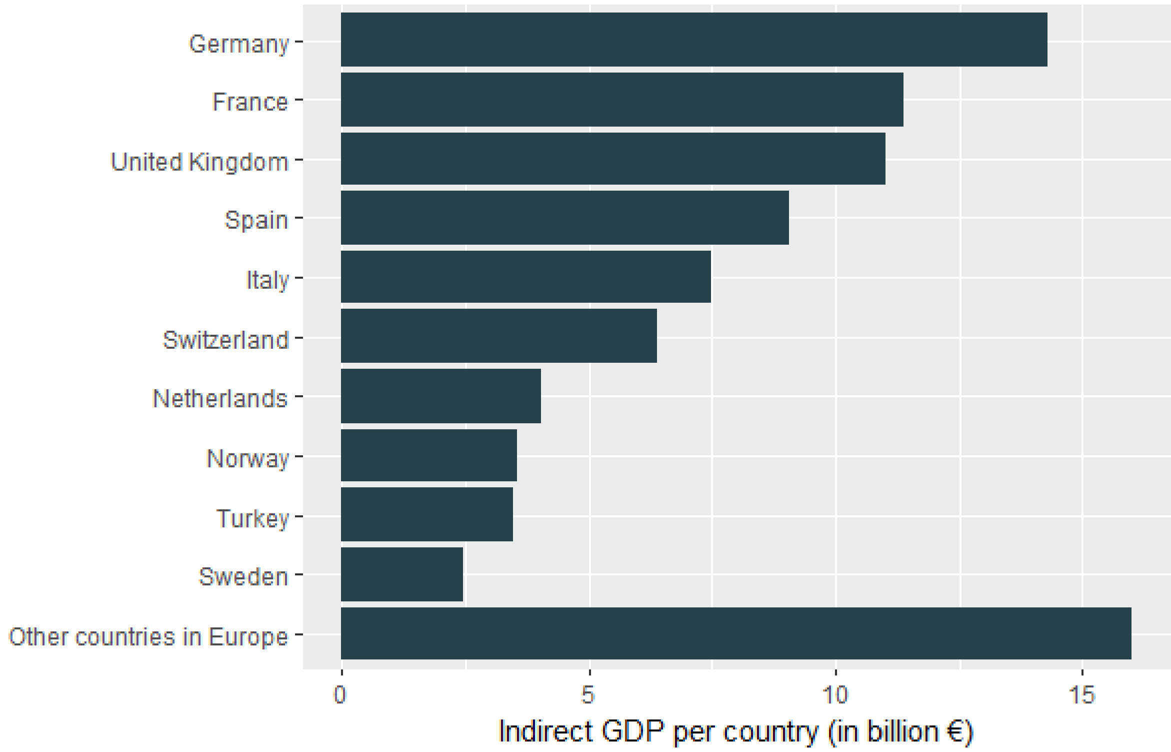


Figure B.5 The indirect impact of airports on employment is sorted according to the level of aviation activity

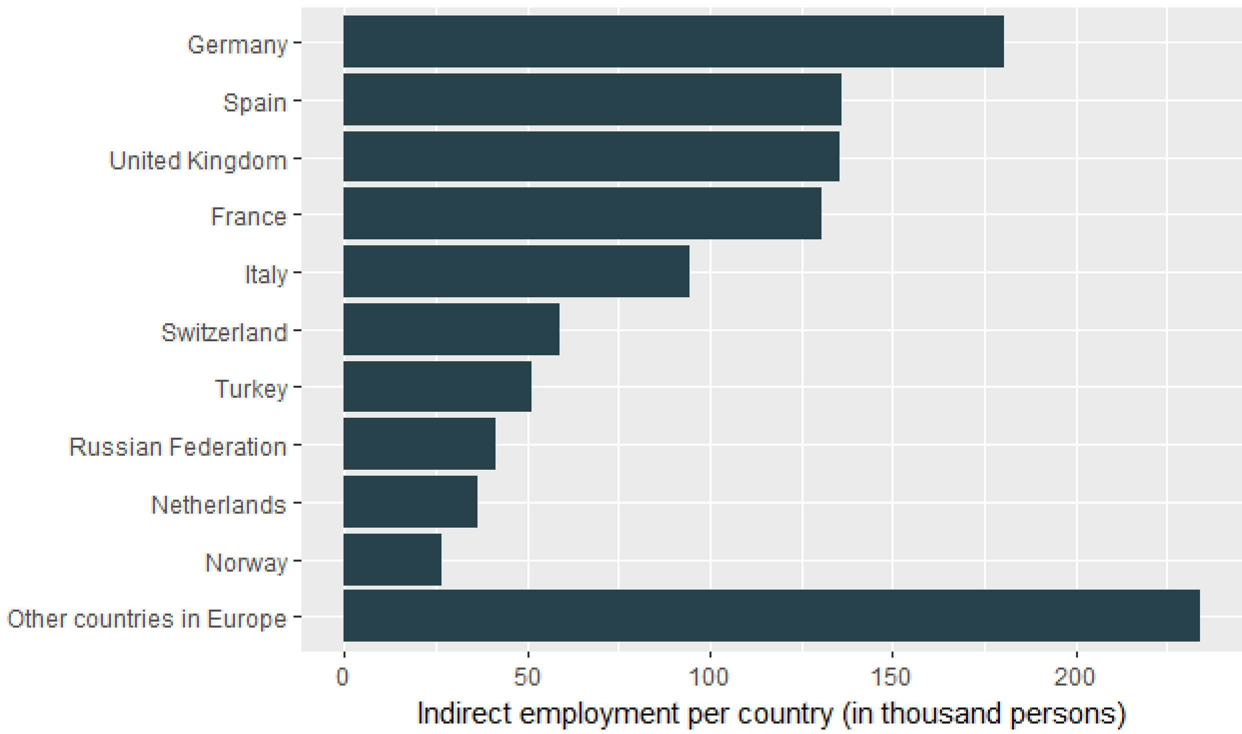


Figure B.6 The induced impact of airports on GDP is highest in Germany, UK and France

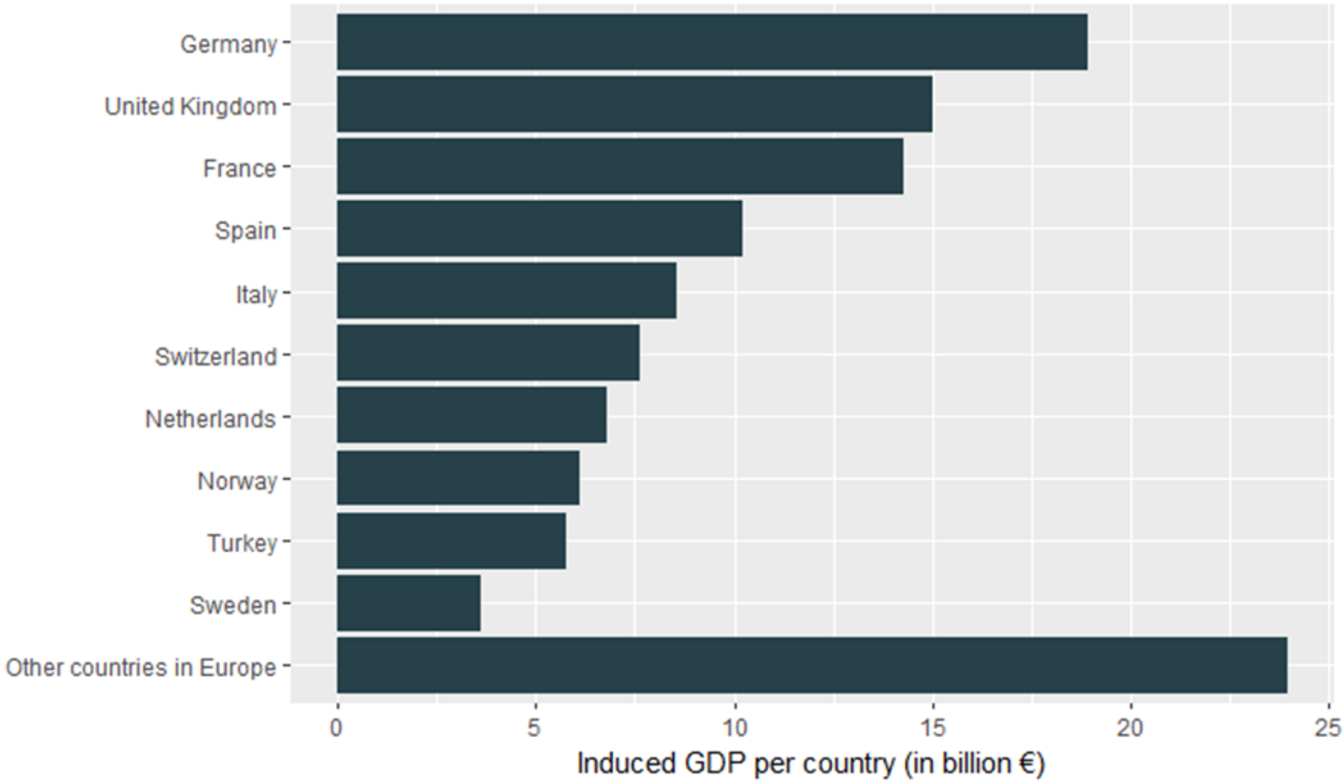


Figure B.7 The induced impact of airports on employment is higher in Spain than in the UK

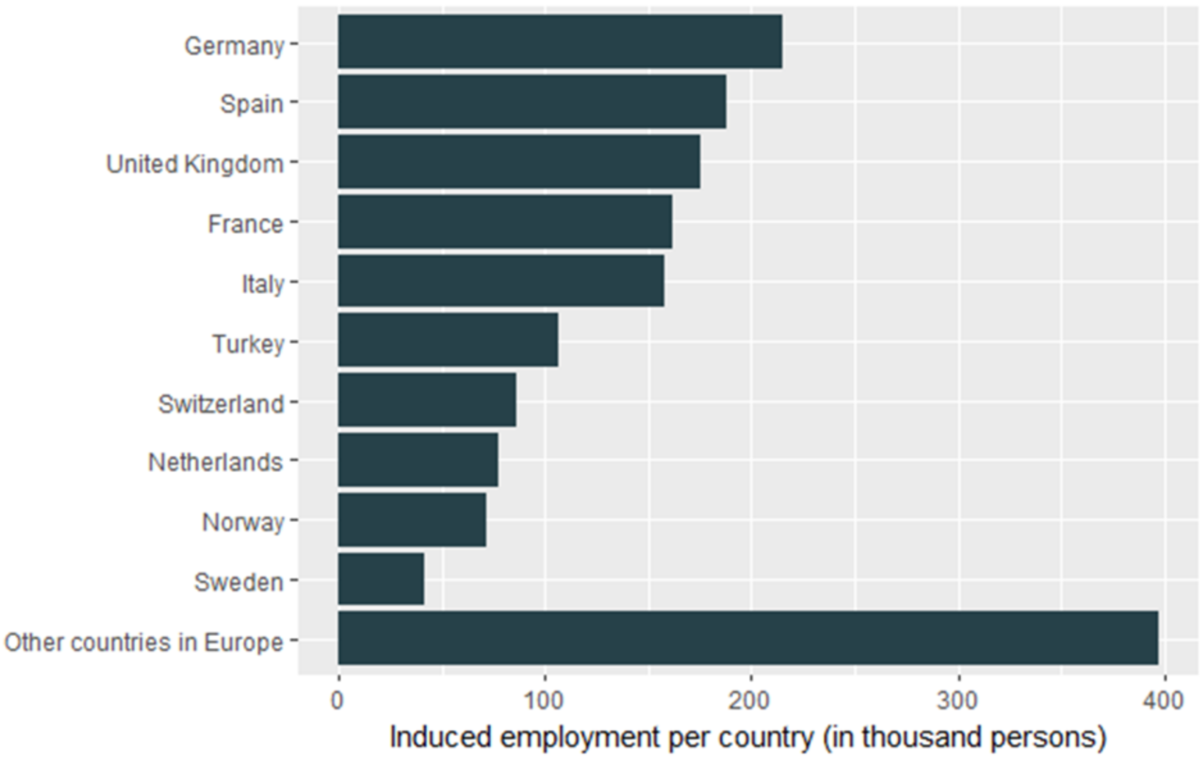


Figure B.8 The tourism impact on GDP is highest for Spain, the United Kingdom and Italy

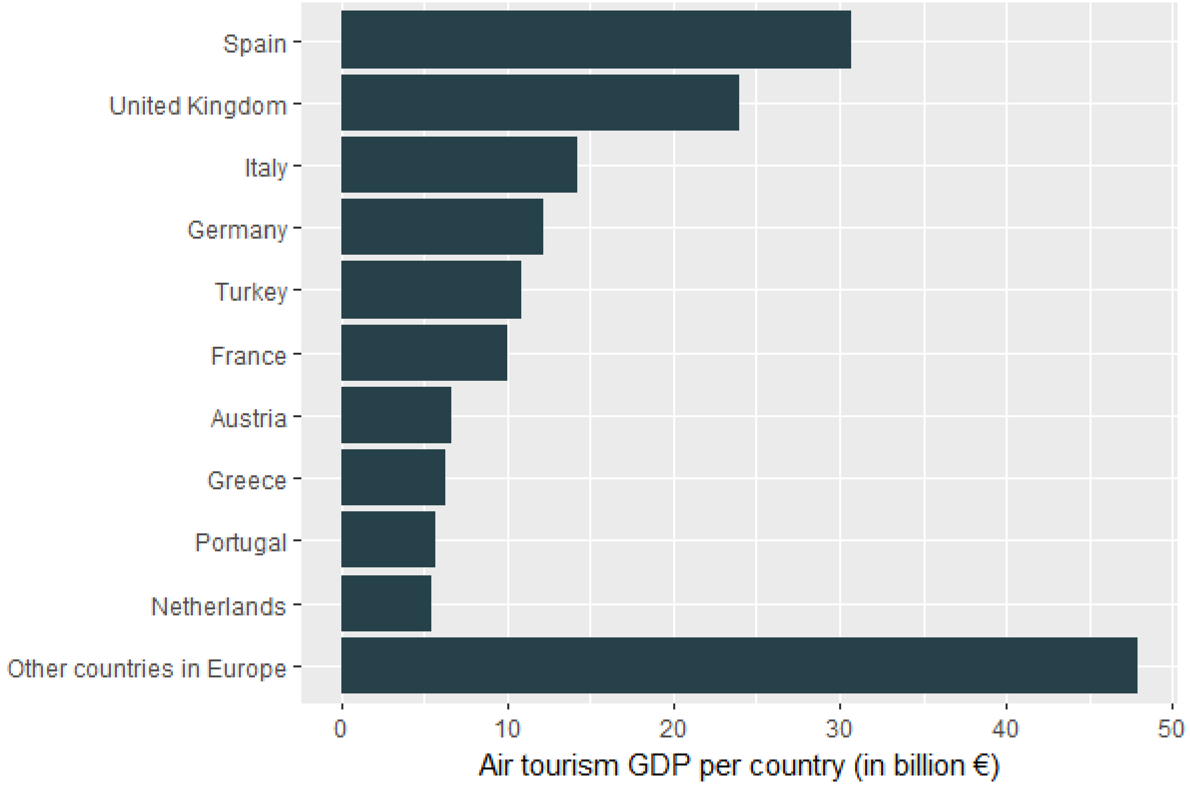


Figure B.9 The tourism impact on employment is highest for Spain, the United Kingdom and Italy

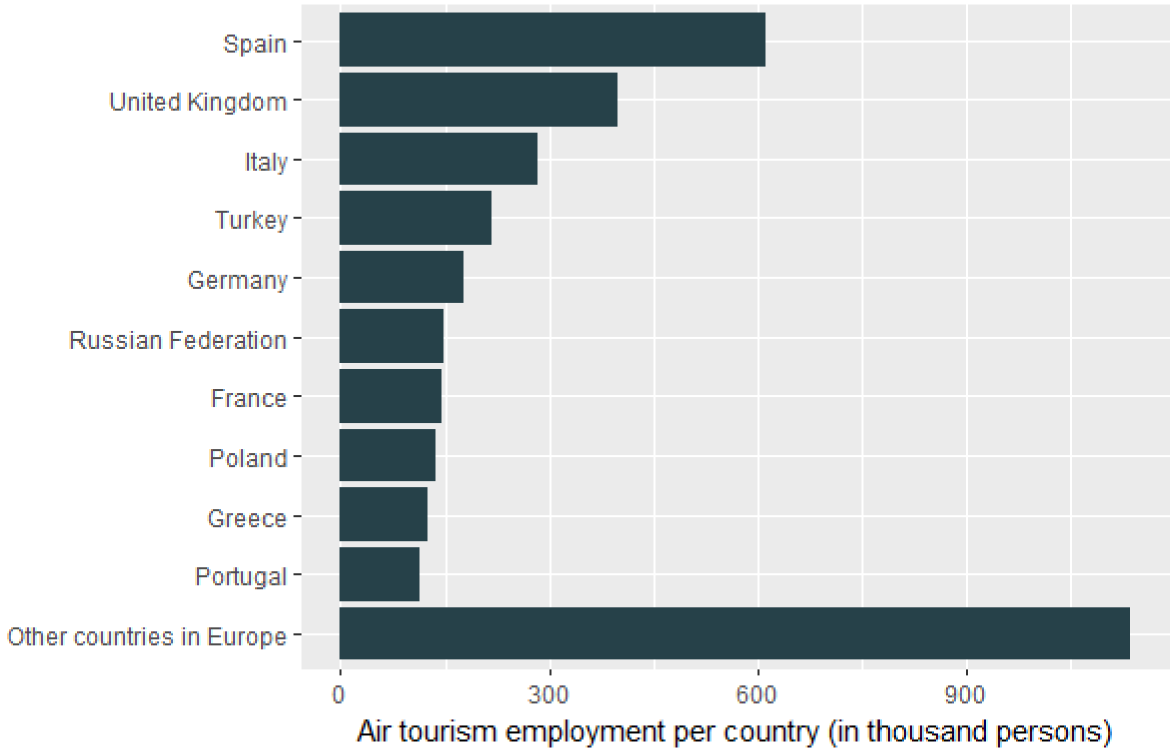
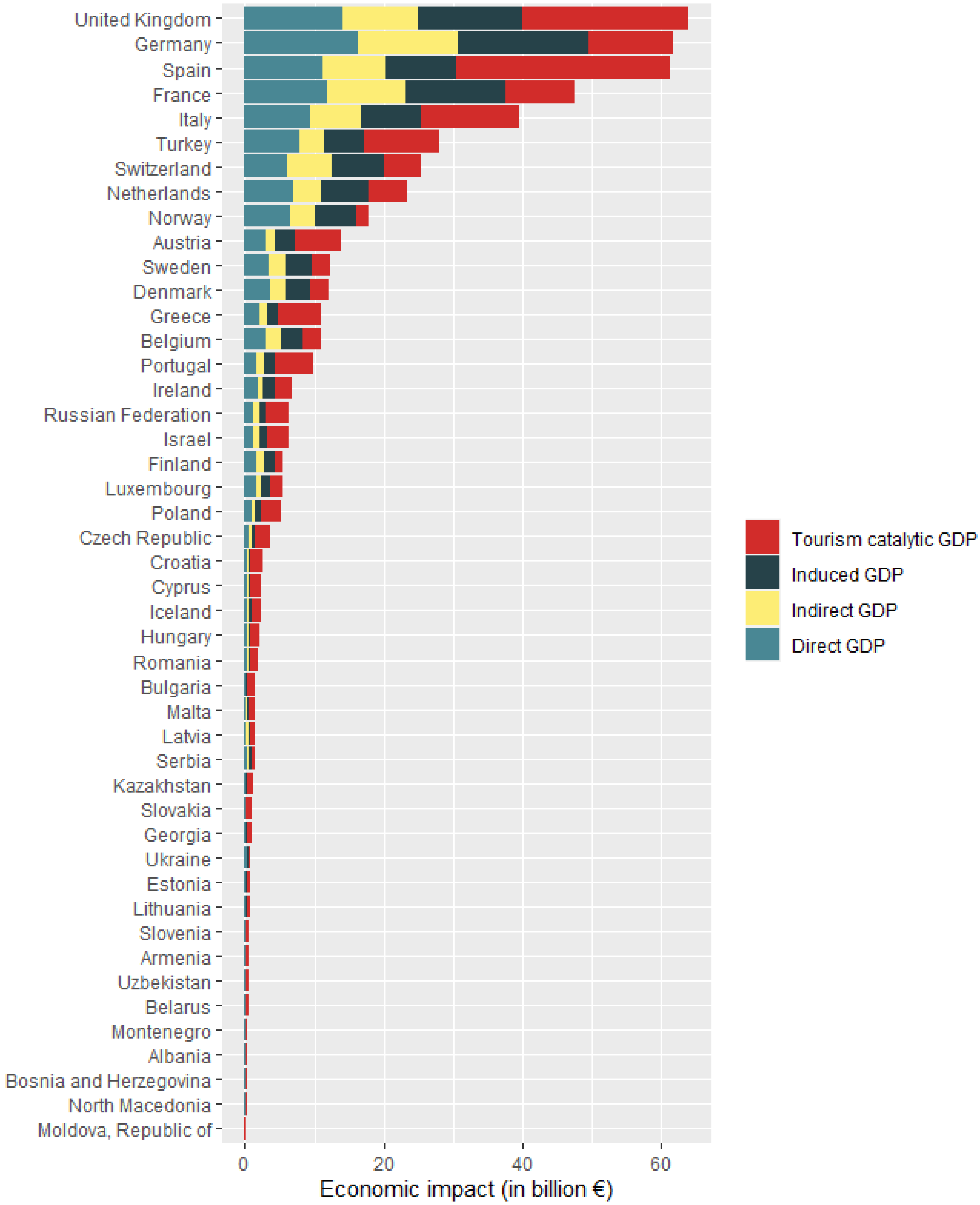
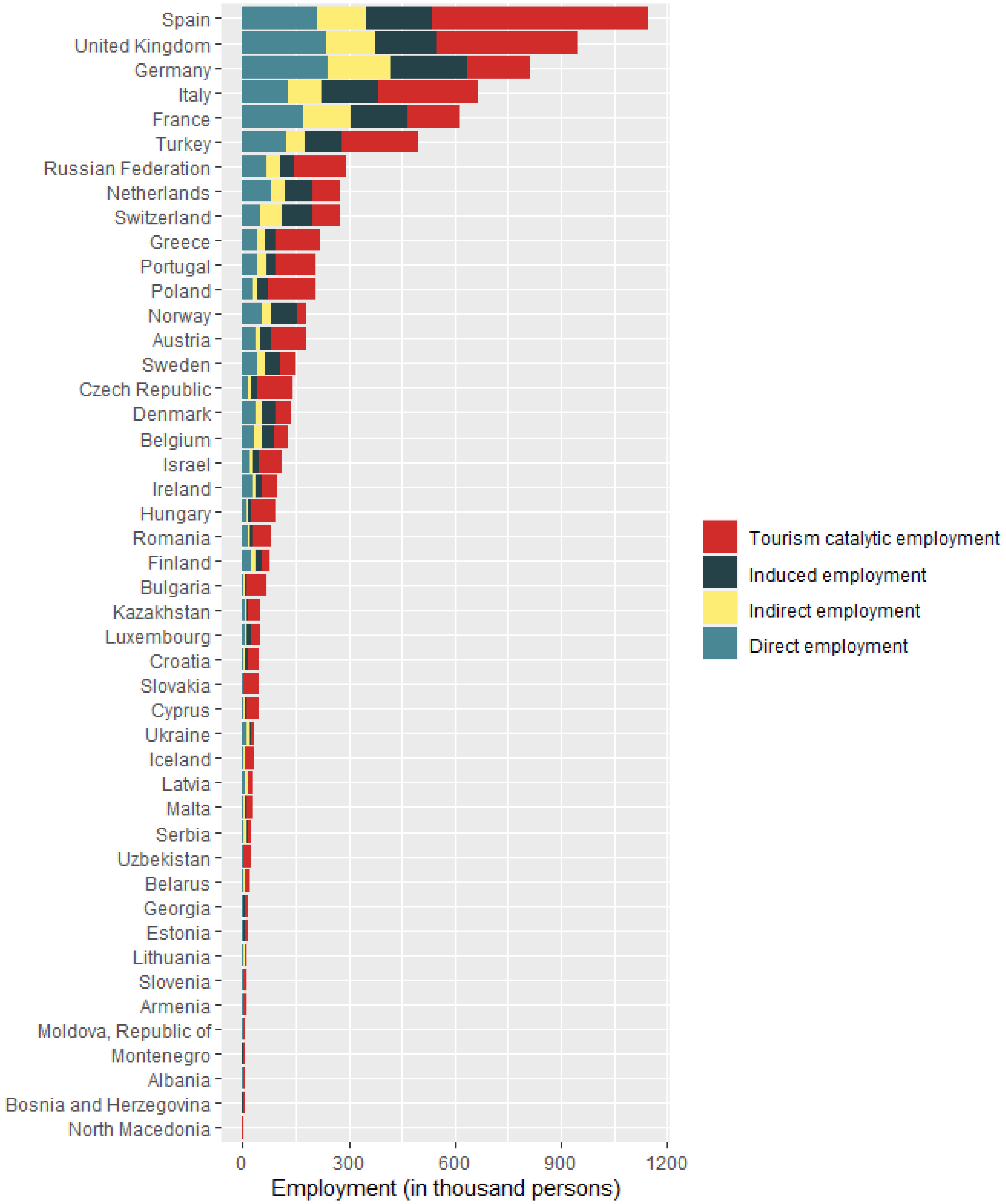


Figure B.10 Direct, indirect, induced and tourism catalytic GDP impact per country



Source: Analysis SEO Amsterdam Economics based on survey among ACI EUROPE's airport members

Figure B.11 Direct, indirect, induced and tourism catalytic employment impact per country



Source: Analysis SEO Amsterdam Economics based on survey among ACI EUROPE's airport members

Table B.2 The total impact on GDP and employment is highest in Germany

Country	GDP impact (in billion €)						Employment impact (in thousand persons)					
	Direct	Indirect	Induced	Tourism	Agglo-mera-tion	Total	Direct	Indirect	Induced	Tourism	Agglo-mera-tion	Total
Albania	0.1	0.0	0.1	0.1	-	**0.4**	1.6	0.8	1.4	2.8	-	**6.5**
Armenia	0.1	0.0	0.1	0.4	-	**0.6**	1.5	0.6	1.2	7.4	-	**10.7**
Austria	3.0	1.4	2.7	6.7	6.7	**20.5**	36.4	13.8	31.1	97.6	77.9	**256.9**
Belarus	0.1	0.1	0.1	0.2	-	**0.5**	4.1	2.0	2.6	11.2	-	**19.9**
Belgium	3.0	2.3	3.2	2.6	7.9	**18.9**	32.0	22.5	36.4	37.5	85.7	**214.0**
Bosnia	0.0	0.0	0.0	0.3	-	**0.3**	0.6	0.2	0.4	5.2	-	**6.4**
Bulgaria	0.1	0.1	0.1	1.3	1.1	**2.6**	5.8	2.2	3.3	58.4	-	**69.7**
Croatia	0.4	0.2	0.3	1.6	0.8	**3.3**	6.5	2.7	5.2	32.6	-	**47.1**
Cyprus	0.3	0.2	0.3	1.5	0.3	**2.7**	5.4	3.3	5.1	30.6	-	**44.3**
Czech Republic	0.5	0.5	0.5	2.2	3.9	**7.5**	14.8	10.7	17.1	99.5	-	**142.1**
Denmark	3.7	2.2	3.5	2.6	5.0	**17.1**	36.4	18.1	41.2	43.1	50.9	**189.8**
Estonia	0.1	0.1	0.1	0.5	0.5	**1.3**	2.8	1.9	1.3	8.7	11.7	**26.2**
Faroe Islands	0.0	-	-	-	-	**0.0**	0.2	-	-	-	-	**0.2**
Finland	1.6	1.1	1.7	1.1	3.9	**9.4**	23.9	12.8	19.5	18.6	45.7	**120.4**
France	11.9	11.4	14.3	10.0	40.0	**87.6**	173.7	130.8	162.0	146.0	480.2	**1092**
Georgia	0.2	0.1	0.1	0.6	0.3	**1.2**	2.8	1.3	2.3	11.0	-	**17.4**
Germany	16.4	14.3	18.9	12.2	59.2	**121.0**	239.3	180.2	215.2	177.4	756.2	**1563**
Gibraltar	0.0	-	-	-	-	**0.0**	0.1	-	-	-	-	**0.1**
Greece	2.1	1.0	1.6	6.3	2.8	**13.8**	43.0	20.5	29.3	125.1	69.0	**286.8**
Hungary	0.3	0.1	0.2	1.5	2.6	**4.7**	11.1	3.9	8.0	69.1	80.6	**172.6**
Iceland	0.4	0.2	0.4	1.3	0.4	**2.7**	3.4	1.8	4.2	22.3	3.5	**35.3**
Ireland	2.0	0.7	1.6	2.6	5.7	**12.5**	30.0	6.5	19.1	42.4	40.6	**138.6**
Israel	1.2	0.9	1.1	3.1	-	**6.3**	20.3	7.0	20.0	62.1	68.6	**178.0**
Italy	9.3	7.5	8.5	14.2	29.6	**69.2**	130.6	94.4	157.7	282.5	418.8	**1084**
Kazakhstan	0.2	0.1	0.1	0.7	-	**1.2**	9.1	3.3	5.0	33.5	-	**50.9**
Kosovo	0.1	0.0	0.0	-	-	**0.1**	0.9	0.4	0.8	-	-	**2.1**
Latvia	0.2	0.3	0.3	0.7	0.5	**2.0**	7.3	7.1	3.4	11.8	16.3	**45.8**

Lithuania	0.2	0.1	0.2	0.3	0.8	**1.6**	4.0	1.4	1.8	5.8	24.8	**37.8**
Luxembourg	1.7	0.6	1.4	1.7	1.1	**6.5**	7.0	3.0	16.3	24.6	4.5	**55.3**
Malta	0.2	0.2	0.2	0.9	0.2	**1.7**	3.9	2.9	4.0	17.4	-	**28.2**
Moldova	0.0	0.0	0.0	0.1	-	**0.2**	1.6	0.6	0.9	5.4	-	**8.5**
Monaco	0.2	-	-	-	-	**0.2**	2.1	-	-	-	-	**2.1**
Montenegro	0.0	0.0	0.0	0.3	-	**0.4**	0.5	0.2	0.4	6.8	-	**7.8**
Netherlands	7.1	4.0	6.8	5.4	13.6	**36.9**	82.6	36.6	77.3	78.9	143.4	**418.7**
North Macedonia	0.1	0.0	0.0	0.1	0.2	**0.4**	1.0	0.4	0.8	2.2	-	**4.5**
Norway	6.5	3.5	6.1	1.8	7.2	**25.1**	54.6	26.9	71.1	29.4	48.4	**230.5**
Poland	1.0	0.6	0.7	3.0	8.9	**14.1**	28.4	15.7	26.4	135.8	295.9	**502.2**
Portugal	1.7	1.1	1.4	5.7	3.4	**13.4**	41.9	25.0	26.5	113.9	87.8	**295.1**
Romania	0.3	0.2	0.2	1.1	4.1	**6.0**	15.3	6.4	9.1	48.7	-	**79.5**
Russia	1.2	1.0	1.0	3.2	30.6	**36.9**	66.6	41.3	36.2	149.4	-	**293.5**
Serbia	0.3	0.3	0.3	0.4	0.7	**2.1**	5.0	4.9	5.8	8.9	-	**24.7**
Slovakia	0.0	0.0	0.0	0.9	1.6	**2.6**	1.2	0.6	1.0	43.6	-	**46.4**
Slovenia	0.1	0.1	0.1	0.5	0.8	**1.4**	1.4	1.0	1.1	9.5	17.6	**30.5**
Spain	11.2	9.1	10.2	30.7	20.7	**82.0**	211.8	136.4	188.4	611.4	348.7	**1497**
Sweden	3.5	2.5	3.6	2.8	8.2	**20.5**	41.0	22.4	41.9	45.7	91.5	**242.5**
Switzerland	6.1	6.4	7.6	5.3	10.8	**36.1**	52.3	58.9	86.4	76.7	82.5	**356.9**
Turkey	8.0	3.5	5.8	10.9	19.2	**47.2**	123.2	51.2	106.4	216.8	-	**497.6**
Ukraine	0.3	0.2	0.2	0.2	-	**0.8**	13.4	5.4	7.8	7.6	-	**34.1**
United Kingdom	14.0	11.0	15.0	24.0	42.7	**106.8**	237.9	135.7	175.3	398.2	549.2	**1496**
Uzbekistan	0.1	0.0	0.0	0.4	**-**	**0.5**	2.4	0.7	1.3	20.2	-	**24.6**

Source: SEO Amsterdam Economics

Note: The catalytic agglomeration impacts per country are estimated by multiplying total agglomeration impacts for all countries combined (from Appendix E) by the share of the country's GDP / employment in the combined GDP / employment. For fourteen countries, OECD does not provide data about GDP and/or employment. For these countries we do not provide an estimate of the catalytic agglomeration impacts. It mainly concerns small countries.

Table B.3 The gross economic impact of airports as percentage of the total GDP is highest in Malta

Countries	Impact airports as a percentage of:	
	Total GDP	Total employment
Austria	3.7%	4.1%
Belgium	2.4%	2.7%
Bulgaria	2.6%	NA
Croatia	5.3%	NA
Cyprus	11.8%	NA
Czech Republic	1.6%	NA
Denmark	4.2%	4.8%
Estonia	3.1%	2.2%
Finland	2.5%	2.9%
France	2.1%	2.3%
Georgia	5.4%	NA
Germany	1.8%	1.9%
Greece	6.9%	5.6%
Hungary	1.5%	2.0%
Iceland	9.6%	15.9%
Ireland	2.1%	4.3%
Italy	2.3%	2.8%
Latvia	5.1%	3.2%
Lithuania	1.6%	0.9%
Luxembourg	8.5%	19.9%
Malta	12.1%	NA
Netherlands	3.0%	3.4%
Norway	4.4%	6.7%
Poland	1.0%	1.2%
Portugal	5.1%	4.2%
North Macedonia	2.3%	NA
Romania	0.8%	NA
Russian Federation	0.4%	NA
Serbia	3.4%	NA
Slovakia	1.1%	NA
Slovenia	1.5%	1.3%
Spain	5.2%	5.8%
Sweden	2.6%	2.9%
Switzerland	4.1%	5.9%
Turkey	2.6%	NA
United Kingdom	2.6%	3.1%

Note: The gross economic impact is based on the direct, indirect, induced and catalytic tourism impact and therefore excludes the catalytic impact from agglomeration. For fourteen countries, OECD does not provide data about the size of the economy. These countries are missing in this table. It mainly concerns small countries. For some countries OECD only provides the size of the economy in terms of GDP and not in terms of employment.

Source: Analysis SEO Amsterdam Economics based on survey among ACI EUROPE's airport members and data from OECD and UNWTO.

Appendix C Net impact

Methodology: Ordinary Least Squares

Ordinary Least Squares models are utilized to explore the causal relationships between connectivity, passengers and cargo flights and key economic indicators such as GDP per capita and employment. Due to a bi-directional causal relationship between the endogenous variables and the dependent variable, Two-stage least squares estimation is performed with lagged endogenous variables as instrumental variables.

Ordinary Least Squares (OLS) regression is a statistical method primarily used for estimating the relationship between variables, particularly in the context of understanding associations between variables. The goal of OLS is to find the line that best fits the observed data points by minimizing the sum of the squared differences between the observed and predicted values. The focus of this study is on the relationship between connectivity and GDP, therefore, the main specification has the following form:

$$log(GDP_{it}) = \beta_0 + \beta_1 \log(dir.con.\ 150_{it}) + \beta_2 year_t + \beta_3 nuts3_i + e_{it} \quad ,$$

where the dependent variable $log(GDP_{it})$, is the natural logarithm of GDP per capita in NUTS 3 region i and year t; and the independent variable $\log(dir.con.\ 150_{it})$ is the natural logarithm of direct connectivity in 150km radius of a NUTS 3 region. Additionally, year fixed effects $year_t$ are included in the model to correct for time trends and NUTS 3 regional fixed effects $nuts3_i$ are included to correct for time-invariant regional characteristics. The parameters $\beta_0, \dots, \beta_3$ are the coefficients to be estimated, and e_{it} represents the error term. Due to endogeneity concerns, a causal interpretation of the OLS results is not advisable in this context.

Methodology: Two stage – instrumental variables regression

Introduction

The standard OLS regression model does not account for bi-directional causal relationships between variables. It effectively estimates the coefficients of a linear relationship between the independent and dependent variables, assuming a one-way causal relationship from the independent variable to the dependent variable. As there is a bi-directional causal relationship between aviation and economic outcomes (GDP, employment, etc.), OLS regression may produce biased estimates of the coefficients. This is because OLS assumes that the independent variables are exogenous, which may not hold true in the case of bi-directional causality.

To address bi-directional causality in the OLS regression, a two stage instrumental variable regression approach is used. Two-stage least squares (2SLS) regression is an econometric technique used to estimate the parameters of a linear regression model when the independent variables are potentially endogenous (correlated with the error term). It is commonly employed in situations where instrumental variables are available to address endogeneity issues, such as in the presence of bi-directional causality.

Instrumental variables regression in aviation research

Obtaining the causal relationship between airport connectivity and economic activity is notoriously difficult. It is typically argued that there is a bi-directional relationship between airport connectivity and economic activity. That is, increases in airport connectivity lead to higher economic output, but higher economic output may also lead to increased connectivity. Moreover, (unobserved) economic shocks, such as a major sport event or the sudden increase in the touristic appeal of a certain location, may influence both economic activity and air connectivity creating a spurious correlation between these two main dependent and independent variables in our econometric models. The conventional way of dealing with this so-called endogeneity issue is the use of instrumental variables. Suitable instrumental variables should be related to airport connectivity, but not (other than through its impact on connectivity) influence the economic output variable of interest. Extant studies in the (scientific) literature have used different instruments. To provide some examples: Brueckner (2003) uses slot constraints, among others; Green (2007) uses historical runway capacity; Alroggen & Malina (2014) use lagged passenger movements; Blonigen & Cristea (2015) and Brugnoli et al. (2018) use quasi-natural experiments exploiting the U.S. Air Deregualtion Act and the de-hubbing of Alitalia at Malpensa airport, respectively; finally, McGraw (2020) uses historical data on landing field locations spanning 1900 – 2010. See Table C.1 for a concise overview of the instrumental variables considered for this analysis and their advantages and disadvantages.

Table C.1 Examples of transport infrastructure instrument variable approaches

Instrument and paper	Advantage	Disadvantage
Runway count and length (Green, 2007)	• Exogenous	• Runway capacity and runway length both have opportunity cost (investment and maintenance) that might have an effect on GDP • Almost no variation
Slots Brueckner (2003)	• Available • Indicates that region has slot controlled airport	• Poor correlation low CNU, i.e. small airports • Variation also due to geography • Dummy • No variation over time
Historical Infrastructure Network (Adler, Pasidis, Levkovich, Lembcke, & Ahrend, 2020)	• Directly available but not for non-EU	• Entanglement of ownership • Requires forward spin to create time dimension
Lagged passenger movements (Allroggen & Malina, 2014)	• Available	• Endogeneity concerns
Quasi-natural experiments (Brugnoli, Dal Bianco, Martini, & Scotti, 2017); (Blonigen & Cristea, 2012)	• Exogenous	• Research question requires large geographic variation • no suitable example for high correlation with CNU at this scale and over so many years
Lagged population growth (Green, 2007)	• Available	• Endogeneity concerns
Digitized historical aviation data (McGraw, 2020)	• Exogenous	• Largest cities have few, if any, credible counterfactual cities available, this research design necessitates a focus on mid-sized and smaller airports.

Source: SEO Amsterdam Economics

Instrumental variables approach applied in this study

In the main model, the third lag of the endogenous variable is used as an instrument, see the following section. Lagged endogenous variables are commonly used as instruments, as they help to address directional relationship-related endogeneity (i.e. both CNU (i.e. connectivity units) affecting GDP as well as GDP affecting CNU) and alleviate concerns over omitted variables.

In the first stage, the relationship between the potentially endogenous variable $log(dir.con.\ 150_{it})$ and its instrumental variable $log(dir.con.\ 150_{it-3})$ is estimated. Also in this model, year fixed effects $year_t$ and NUTS 3 regional fixed effects $nuts3_i$ are included. The equation for the first stage of our main specification can be represented as:

$$log(dir.con.\ 150_{it}) = \beta_0 + \beta_1 log(dir.con.\ 150_{it-3}) + \beta_2 year_t + \beta_3 nuts3_i + e_{it}$$

In the second stage, the predicted values of the potentially endogenous variable obtained from the first stage $\log(dir.con.\ 150_{it})$ are used along with the residuals of the first stage regression $log(residuals_{it})$ and the fixed effects. Specifically, a model of the following form is estimated for our main specification:

$$log(GDP_{it}) = \beta_0 + \beta_1 log(residuals_{it}) + \beta_2 \log(dir.con.\ 150_{it}) + \beta_3 year_t + \beta_4 nuts3_i + e_{it}$$

In both stages, population weights are added to the regression models to give more weight to NUTS 3 regions with larger populations, thereby ensuring that each observation contributes proportionally to the overall variance in the regression model. Furthermore, the errors are clustered on the NUTS 2 region-level to account for heteroskedasticity and regional correlation of the residuals.

The equations above represent our main model specification, but various models are estimated (i.e. direct connectivity on employment, passengers on GDP, etc.). When there is more than one endogenous regressor, multiple instrumental variables are employed. For example, when airport and hub connectivity are included in one model, two lagged instruments are used, i.e. one for each endogenous regressor.

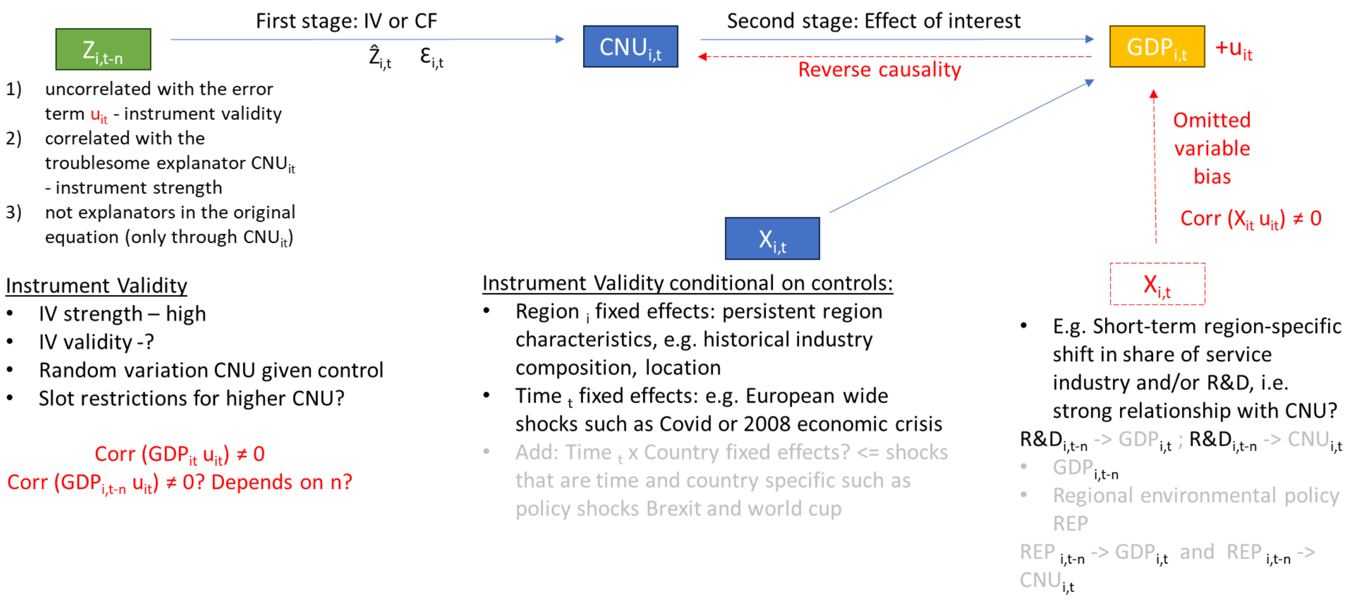
The results of the 2SLS models are paramount for inference and policy implications, as they offer a more rigorous approach to identifying causal effects and addressing endogeneity issues.

For this analysis, lagged connectivity, lagged passengers and historical infrastructure were applied as instruments since the other instruments were either unavailable or not applicable in this spatiotemporal context. See for example (Angrist, 1996) or (Wooldridge, 2015) for details on instrumental variable approach and control function estimation. A visual summary of the control function approach in this context is presented in Figure C.1.

The F-statistic in Table C.5 and 0 is computed based on the regression results from the first stage. Specifically, it compares the overall fit of the regression model with the instruments to the fit of a restricted model where the coefficients of the instruments are constrained to be zero. The null hypothesis for the F-test is that all coefficients of the instruments are jointly equal to zero, indicating that the instruments are not relevant for explaining the variation in the endogenous variables. The alternative hypothesis is that at least one coefficient is nonzero, suggesting that the instruments are relevant.

If the F-statistic is statistically significant (i.e., if the p-value is below a chosen significance level, typically 0.05), then the null hypothesis is rejected. This indicates that the instruments are jointly significant and considered strong for the IV estimation. Conversely, if the F-statistic is not significant, it suggests that the instruments are weak and may not be suitable for addressing endogeneity. Additionally, a larger F-statistic indicates stronger evidence against the null hypothesis of weak instruments.

Figure C.1 Instrumentation and control function approach



Source: SEO Amsterdam Economics

Data merging

Panel data

Panel data models are used to estimate the causal linkages of connectivity, passengers, cargo and the dependent variables GDP per capita and employment. As an input for these models a dataset is designed that contains direct, indirect, hub connectivity and airport connectivity, total cargo in tons and number of total passengers for airports within 50, 100, 150 and 200km radius as well as GDP, employment and population size in the NUTS 3 region of the airports. We combine datasets from Eurostat, the Official Airline Guide (OAG), Airports Council International (ACI), OpenFlights.org and the Geographic Information System of the Commission (GISCO).

As a first step, we create a panel dataset containing the economic variables as well as geographical coordinates per NUTS 3 region for the years 2004-2019. We merge data on GDP per capita, employment in thousand persons and population size per NUTS 3 region for the years 2004-2019. GDP, employment and population data is obtained from Eurostat. Afterwards, we merge the economic data per NUTS 3 region with the corresponding geographical coordinates (latitude and longitude) of the NUTS 3 regions. The geographical coordinates per NUTS 3 region are obtained from GISCO.

As a next step, we construct a panel dataset containing all connectivity variables, total air transport movements, total cargo and total passengers per airport for the years 2004-2019 as well as the corresponding geographical coordinates (latitude and longitude). The geographical coordinates per airport are obtained from OpenFlights.org Data on direct connectivity, indirect connectivity and hub connectivity is obtained from SEO. Data on total air transport movements, total cargo and total passengers is obtained from ACI.

Afterwards, we cross join the NUTS 3 regions and the airports codes so that we obtain a dataset containing all possible combinations of NUTS 3 regions and the airports codes. We then add the geographical points per NUTS 3 region and the geographical points per airport. This provides us with a dataset that contains all combinations of airport codes and NUTS 3 codes as well as the latitude and longitude per airport and the latitude and longitude per NUTS 3 region (geographical centroid of the region).

We need to determine which airports are located within a radius of 50, 100, 150 and 200km. For this, we first calculate the distance between the geographical point of an airport x_i and the geographical centroid of a NUTS 3 region y_j using the Haversine formula:

$$D(x_i, y_j) = 2\arcsin\left[\sqrt{sin^2\left(\frac{x_{ilat} - y_{jlat}}{2}\right) + \cos(x_{ilat})\cos\left(y_{jlat}\right)sin^2\left(\frac{(x_{ilon} - y_{jlon})}{2}\right)}\right],$$

where x_{ilat} is the latitude of the location of an airport and x_{ilon} is the longitude of an airport, and where y_{jlat} is the latitude of the central point of a NUTS 3 region and y_{jlon} is the longitude of the centroid of a NUTS 3 region.

Next, we merge back the connectivity variables. Based on the distance we sum up the direct, indirect and hub connectivity for all airports that are within a distance smaller than or equal to 150km ($Distance_{x,y} \leq 150km$). The same aggregation is being done for the other radiuses. This dataset is merged back with the economic data on NUTS 3 level. By doing this, we obtain the final dataset used for the net economic impact analysis. This contains the NUTS 3 region per airport, direct, indirect and hub connectivity, total air transport movements, total cargo and total passengers of airports within 50, 100, 150 and 200km radius as well as GDP per capita, employment and population size of the NUTS 3 region in which an airport is located for the years 2004-2019. We have 24,272 observations.

Data availability

For some countries there is no data available for all of the economic variables on NUTS 3 level, some countries do not have NUTS 3 regions, e.g. Azerbaijan. For the United Kingdom, employment data is only available for the years 2004-2011 on NUTS 3 level. GDP data is not available at Eurostat, so for the United Kingdom we add data on GDP per capita per NUTS 3 region obtained from the Office for National Statistics. As the data is in pounds, we transform it to euro using the average exchange rate in 2019. For Albania and Turkey, employment data is not available on NUTS 3 level. We use the employment rate on country level and estimate employment per thousand people per NUTS 3 region by multiplying the employment rate on country level with the population per NUTS 3 region. For all other countries, we add GDP and population data on country level. Most of these countries are smaller in terms of population and GDP, therefore we assume that the country is one NUTS 3 region.

For some countries the population data contains many missing values, therefore we impute the missing values based on the average population change rate in the years for which we do have population data for a certain region. When estimating panel data models, we weight with population. If we would not impute the missing values we would lose a lot of observations when estimating the models.

Imputation of observations with value zero for direct, indirect and hub connectivity

Our dataset (on airport level) contains many observations with a value of zero for the connectivity variables, for example for the variable direct connectivity 27% of the observations contain a value of zero, for indirect connectivity this percentage is 36% and for hub connectivity the percentage is 70% for the period 2004-2019. An explanation for this is that some airports have not been member of ACI over the whole period. For these airports, connectivity is zero until the airport becomes a member of ACI. Moreover, some airports stopped their activities in certain years. Furthermore, some airports only offer direct flights and therefore the indirect and hub connectivity at those airports is zero, e.g. Vadsø airport in Norway or Monaco Heliport. Some airports did operate flights but have a connectivity of zero for certain years. Including these observations in our model would bias the results, therefore we impute those observations in the following way. First, we divide direct, indirect and hub connectivity in categories based on quantiles. The categories are fixed and based on the data for 2019 as we have most non-zero observations for this year. As a next step, we check whether the variable total air transport movements has a positive observation for an airport in a certain year while direct connectivity is zero. If this is the case, direct connectivity is replaced with the value for total air transport movements. All other observations with value zero for direct, indirect and hub connectivity are predicted based on a linear model, containing direct, indirect or hub connectivity as dependent variable and the category for direct, indirect or hub connectivity and air movements as independent variables and year and country fixed effects. Only observations with value zero are predicted if the number of passengers is positive to avoid the imputation of observations with a positive value that are truly zero. To avoid this, we also set a threshold of at least 28 direct flights per week and 22 indirect flights, if the number of weekly flights is lower, observations with value zero are not replaced. For hub connectivity the threshold is 1000 hub connections per week and the value for direct connectivity must be positive.

Before the imputation, the dataset contains 448 airports, after the imputation the dataset contains 519 airports. In total, 1,273 observations got imputed which is 16% of the data. We remove airports that have observations of value zero for all years. We have a balanced panel as we have observations for every airport for every year.

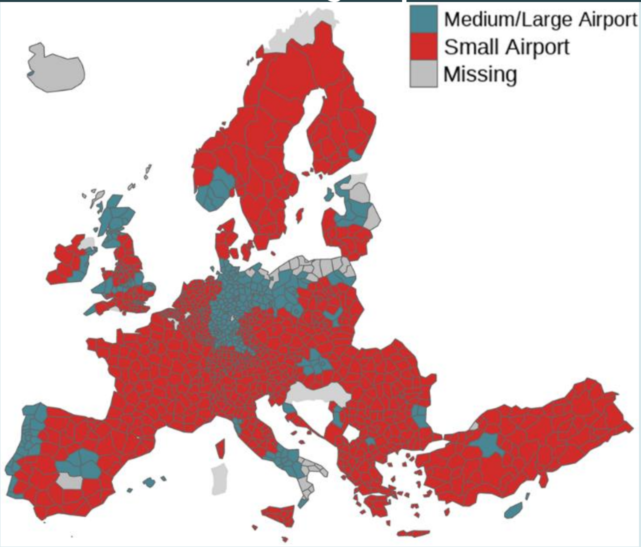
On NUTS 3 level

We calculate connectivity per NUTS 3 region in 50, 100, 150 and 200km radius. For some regions there is no airport within these radiuses and therefore the value for connectivity is zero. We exclude observations with value zero for connectivity from our analysis by using a logarithmic transformation of the data. There are several reasons for excluding observations with a value of zero for connectivity. Firstly, we only want to estimate the effect of connectivity on GDP, we do not want to include in the model whether it has an effect if there is an airport in a region or not. Furthermore, the method should be consistent with the previous SEO study from 2015. In the previous report, connectivity and the economic variables have been derived in a circle of 100km from the airport, these variables have not been derived per NUTS 3 region. For airports that have not been an ACI member during the whole period, there is a jump in the data if an airport becomes an ACI member. Including these observations would bias the results. We also exclude observations with a value of zero for statistical reasons. The data is skewed to the right when we do not exclude observations with a value of zero. This would lead to a downward bias when estimating panel data models.

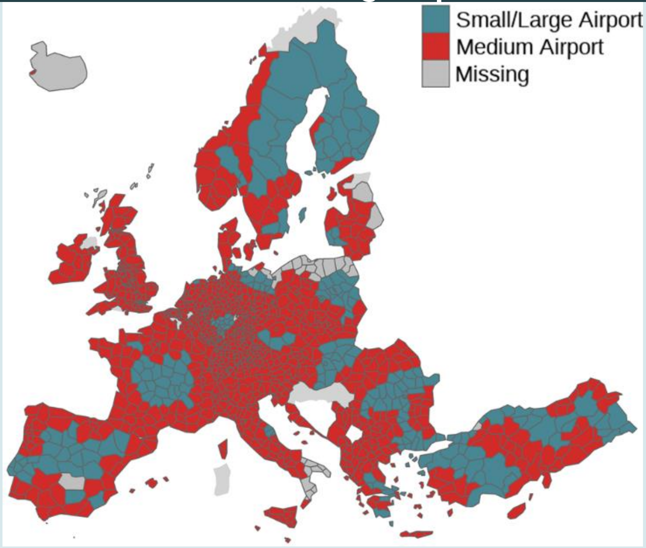
Maps of distribution of airports by size

Figure C.2 Small and medium sized airports usually exist in regions without large airports and vice versa.

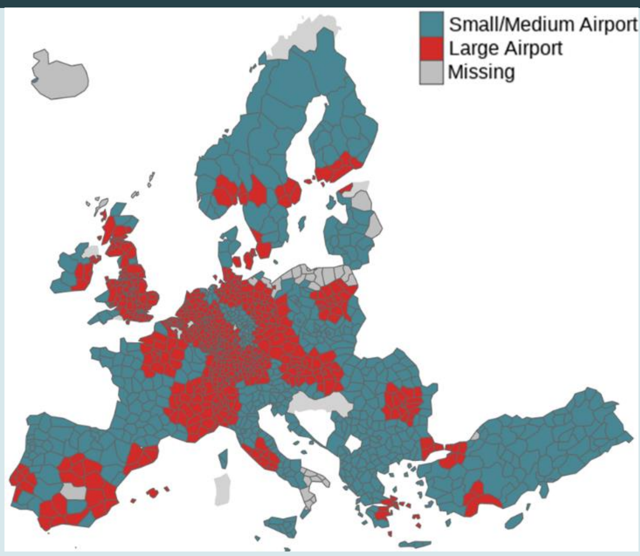
NUTS 3 regions with a small airport (can include medium/large airport)



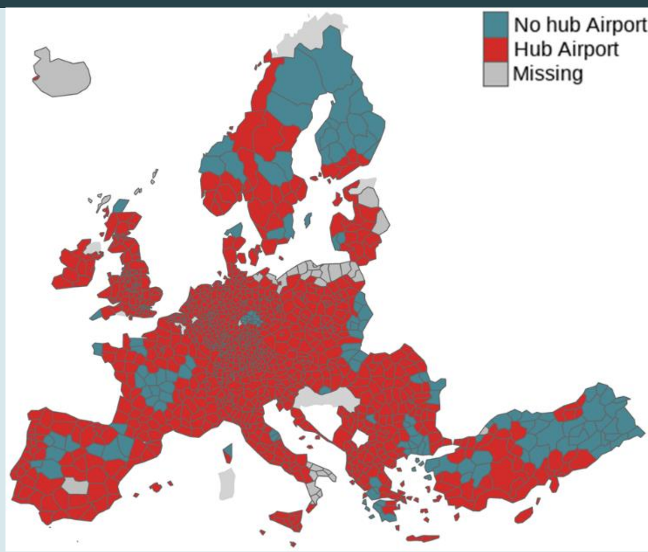
NUTS 3 regions with a medium size airport (can include small/large airport)



NUTS 3 regions with a large airport (can include small/medium airport)



NUTS 3 regions with a hub airport



Summary statistics of data for net impact

Table C.2 Summary statistics connectivity, passengers and cargo data, with LHR airport as a comparison

	Direct connectivity 150km	Indirect connectivity 150km	Hub connectivity 150km	Airport connectivity 150km	Number of passengers 150km (per year)	Number of cargo flights 150km
Min.	2	1	1	2	1354	1
Max.	14,238	31,278	98,404	40,646	209,628,287	148
Median	1,876	4,115	1,341	5,406	16,442,903	59
Mean	2,840	6,293	14,063	8,121	31,766,113	940
LHR (airport)	4,676	12,034	22,399	15,543	65,386,484	47

Table C.3 Summary statistics connectivity, passengers and cargo data by airport size

Airport size	Total number of airports	Average direct connectivity (in CNU per week)	Average indirect connectivity (in CNU per week)	Average hub connectivity (in CNU per week)	Average airport connectivity (in CNU per week)	Average number of passengers (per year)	Average number of cargo flights (per week)
Large	48	2,317	5,195	9,424	7,511	30,643,633	52
Medium	166	371	636	69	1,007	4,115,208	15
Small	284	31	44	0	76	255,342	3
All airports	498	351	710	896	1,060	4,305,568	13

Table C.4 Summary statistics GDP, population, employment

Total GDP (in bln €)	Average GDP per capita	Total population	Total employment*
18,088	27,760	616,298,783	226,945,400

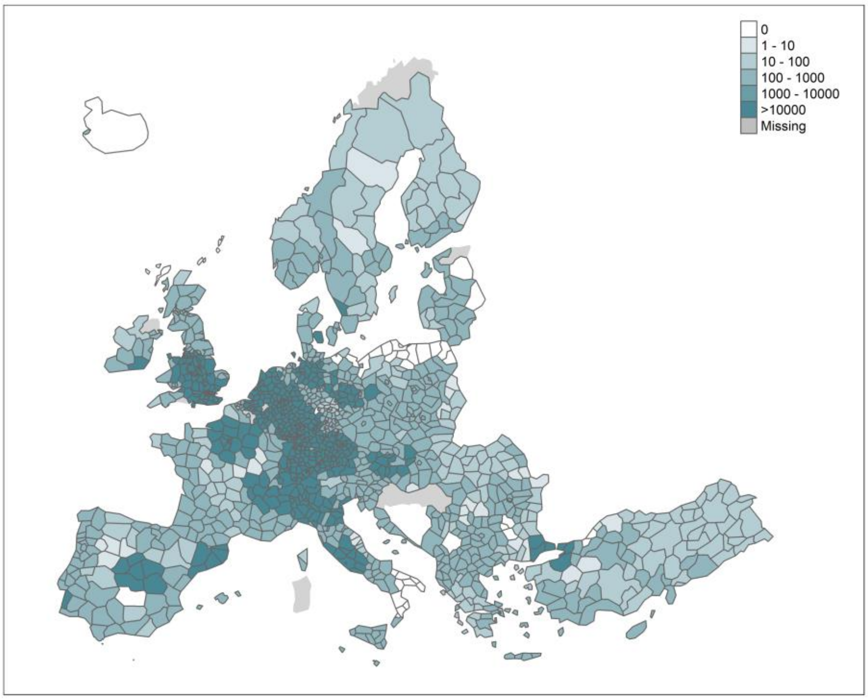
Notes: All information in this table is for 2019. All monetary values are expressed in 2022 €.

*Employment is not available for all NUTS 3 regions

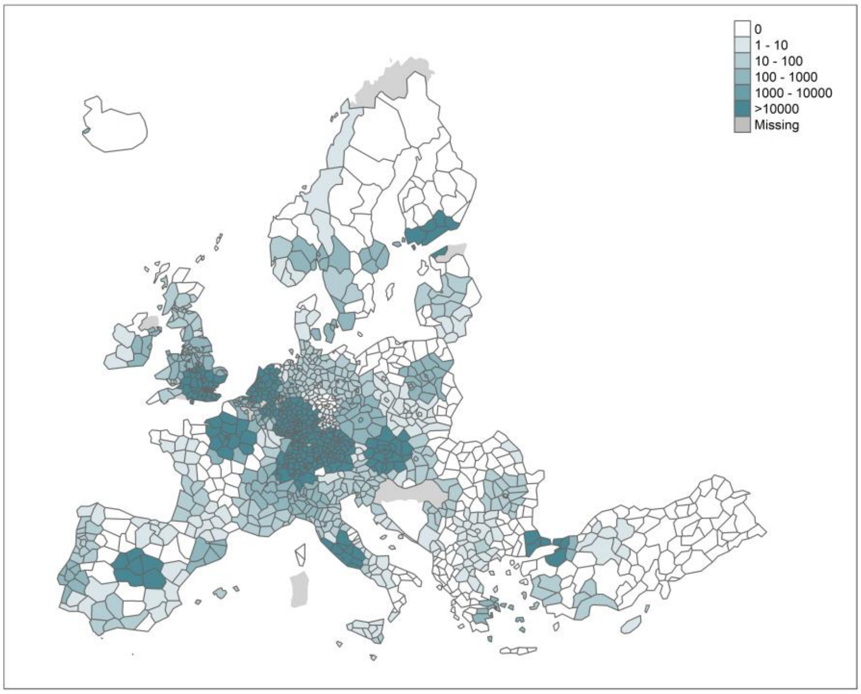
Airport and hub connectivity

Figure C.3 Hub connectivity is highest at economic centers

Airport connectivity (2019)



Hub connectivity (2019)



Additional net results

Table C.5 Connectivity has a significant positive effect on GDP per capita

GDP per capita (log)	Model 1 OLS	Model 2 2SLS	Model 3 OLS	Model 4 2SLS	Model 5 OLS	Model 6 2SLS
Dir. con. 150km (log)	0.092*** (0.011)	0.047* (0.021)				
Airport con. 150km (log)			0.102*** (0.011)	0.068** (0.024)		
Hub con. 150km (log)			-0.004 (0.005)	0.000 (0.018)		
Passengers 150km (log)					0.052*** (0.011)	-0.065* (0.032)
Intercept	9.224	9.451	9.068	9.320	9.056	10.854
Adjusted R2	0.989	0.988	0.989	0.989	0.989	0.987
Within R2	0.051	0.530	0.055	0.057	0.033	0.433
F-test 1st stage		7,396		†		9,546
N	18,538	18,538	18,538	18,538	18,239	18,239
Note:	*p<0.05; **p<0.01; ***p<0.001.All models contain country and year Fixed Effects and are weighted by population. Standard errors are clustered by NUTS 2. †Airport CNU: 0.773, Hub CNU: 0.582					

Table C.6 Connectivity and passengers have a positive significant effect on employment

Employment (log)	Model 7 OLS	Model 8 2SLS	Model 9 OLS	Model 10 2SLS
Dir. con. 150km	0.112*** (0.017)	0.158*** (0.022)		
Passengers 150km			0.051*** (0.015)	0.062** (0.020)
Intercept	3.952	3.625	3.900	3.736
Adjusted R2	0.999	0.999	0.999	0.999
Within R2	0.185	0.331	0.089	0.270
F-test 1st stage		45,732		44,938
N	15,980	15,980	15,709	15,709
Note:	*p<0.05; **p<0.01; ***p<0.001. All models contain country and year Fixed Effects and are weighted by population. Standard errors are clustered by NUTS 2.			

Table C.7 Cargo movements have no clear statistically significant effect on GDP per capita.

GDP per capita (log)	OLS	2SLS	OLS	2SLS
Dir. con. 150km -small (log)	-0.002 (0.004)	-0.009 (0.013)		
Dir. con. 150km -medium (log)	0.020 (0.012)	0.006 (0.016)		
Dir. con. 150km -large (log)	0.097*** (0.023)	0.037 (0.037)		
Dir. con. 150km (log)			0.114*** (0.028)	-0.076 (0.166)
Cargo flights 150km (log)			0.021 (0.011)	0.180*** (0.031)
Intercept	9.345	9.711	9.047	9.835
Adjusted R2	0.989	0.989	0.990	0.990
Within R2	0.019	0.0305	0.036	0.058
F-test	0.733, p = 0.824	0.740, p = 0.817	0.879, p = 0.675	0.899, p = 0.655
N	18,538	18,538	15,214	15,214
Note:	*p<0.05; **p<0.01; ***p<0.001.All models contain country and year Fixed Effects. Standard errors are clustered by NUTS 2.			

Robustness checks

As robustness checks, models with other specifications are estimated. Firstly, models with connectivity in different radiuses (50, 100, 150 and 200km) are estimated. A 150km radius is chosen for the main specification as this is the most robust specification. Furthermore, several time lags are used as instrumental variables (lag 1 until lag 10). The models instrumented with the third lag are most robust. As an alternative instrument, the number of passengers and historic rail connectivity is used. Moreover, models are estimated with different subsets of countries. For example, models are estimated only with northern European countries, Southern European countries or Eastern European countries. Also, separate models are estimated for each country. Additionally, different subsets of years are used, for example, subsets that only include observations in the years before or after the global financial crisis in 2007/2008.

In general, the robustness checks indicate sensitivity to spatial variations, particularly in smaller countries where the instrument may not be equally effective across all regions. While conducting a country-level analysis would require tailored instruments for different regions, it exceeds the scope of this study. However, within our defined geographical context and timeframe, the instrument demonstrates strength, affirming the reliability of the findings of this study.

Appendix D Variables for broad societal impact

Social Sustainability

SDGs — Data and Approach

1 NO POVERTY; 2 ZERO HUNGER

- Poverty measure (poverty headcount ratio)
  - Variable definition: Percentage of population that has only $2.15 or less per day (below poverty line)
  - Source: Worldbank

3 GOOD HEALTH AND WELL-BEING

- Life satisfaction:
  - Variable definition: Self-assessed overall life satisfaction of persons on a scale from 0 to 10.
  - Source: Eurostat

4 QUALITY EDUCATION

- Student mobility rate
  - Variable definition: Number of students from abroad studying in a given country, expressed as a percentage of total tertiary enrolment in that country
  - Source: Worldbank

5 GENDER EQUALITY; 10 REDUCED INEQUALITIES

- Gender gap equality (employment)
  - Variable definition: 100 minus the difference in percent between the share of working man and women.
  - Source: Worldbank

8 DECENT WORK AND ECONOMIC GROWTH

- Foreign Direct Investment (FDI)
  - Variable definition: Cross-border investment (net inflows)
  - Source: Worldbank

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

- Gross domestic expenditure on Research & Development (GERD)
  - Variable definition: Total expenditure on R&D in a country ($)
  - Source: Eurostat

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

- Government effectiveness
- Variable definition: Perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies.
  - Source: Worldbank

17 PARTNERSHIPS FOR THE GOALS

- Trade
  - Variable definition: Sum of exports and imports ($)
  - Source: Worldbank

Appendix D.1 Additional estimations for broad impact

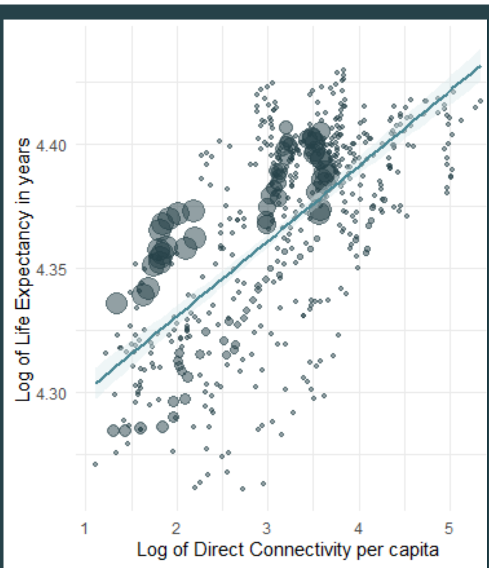
Life expectancy

Previous research has not established a clear link between air connectivity and life expectancy. However, there is a positive correlation (56%) between air connectivity and poverty (see Table 4.2), measured as the average number of years a person is expected to live. This implies that as connectivity increases, life expectancy tends to increase.

The results from the linear regression models indicate that a 10% increase in direct connectivity is associated with a 0.4% increase in life expectancy. However, this effect is entirely explained by the inclusion of GDP and a time trend in the model. Direct connectivity itself does not directly contribute to higher life expectancy but rather has an indirect positive effect mediated through GDP.

This indirect effect can be elucidated through the mechanism by which GDP influences life expectancy. Several research studies have shown that a higher GDP increases life expectancy (Duba et al., 2018; Miladinov, 2020; Zaman et al., 2017). Higher GDP implies greater economic resources within a country, which can translate into improved access to healthcare services, better healthcare infrastructure, and increased investments in public health initiatives. As a result, individuals have better access to medical treatments, preventive care, sanitation, and nutrition, all of which are critical factors influencing life expectancy. Therefore, while connectivity may not directly impact life expectancy, its influence on GDP indirectly enhances life expectancy by facilitating economic growth and subsequently improving access to healthcare services.

Table D.1 Connectivity raises life expectancy through GDP



Correlation: 0.562

Life expectancy (log)	Model 3	Model 4
Direct connectivity (log)	0.040*** (0.01)	-0.003 (0.002)
GDP per capita (log)	Not included	0.010*** (0.002)
Country fixed effects)[31]	Yes (34 countries)	Yes (34 countries)
Time trend	Not included	0.003*** (0.000)
Intercept	4.28*** (0.010)	-1.153*** (0.152)
Observations	542	542
Adjusted R^2 (%)	0.902	0.980

Note: *p<0.05; **p<0.01; ***p<0.001 and standard errors are shown in brackets;

Source: SEO Amsterdam Economics

[31] Countries included are: Albania, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, United Kingdom.

Appendix D.2 Environmental impact

Climate change

CO_2 emissions were modelled for each flight in 2019. Only departing flights were considered to prevent double counting. The number of departing flights was obtained from OAG's Schedule Analyser. As OAG provides scheduled flights, a correction had to be made for flight cancellations and unscheduled flights. Therefore, the scheduled flight movements for each airport were scaled to the airport's actual flight movements in 2019 using data received from ACI EUROPE.

CO_2 emissions are directly related to fuel consumption. Therefore, CO_2 emissions per flight are obtained by multiplying fuel consumption with the appropriate emission factor for CO_2. Fuel consumption for each departing flight was modelled using a methodology which corresponds to the methodology used in Eurocontrol's Small Emitters Tool (SET). In this methodology, fuel consumption is estimated based on flight distance and the aircraft type used.[32] Flight distance was calculated as the great circle distance between the origin and destination airports as provided by OAG. A distance of 95 kilometers was added to the great circle distance (as suggested by the SET). Data on aircraft types are available from the OAG schedule data. Fuel consumption was converted to CO_2 emissions using emission factors of 3.15 for jet and turboprop aircraft and 3.10 for piston aircraft (as suggested by the SET).
The non-CO_2 impacts were derived from the CO_2 emissions. Based on the latest scientific evidence it was assumed that the non-CO_2 impacts – in terms of CO_2 equivalent units or CO_2e – are twice as large as the CO_2 impacts (Lee et al., 2021). However, it should be noted that large uncertainties remain regarding the warming impact of non-CO_2.[33]

Air pollution

Pollutant emissions around airports were modelled for each individual airport in 2019 using the FLAPS.25 model. FLAPS.25 is a state-of-the-art model specifically designed to estimate local airport emissions. The model provides a complete estimation of emissions caused by aircraft operations as it not only assesses the emissions from the aircraft's main engines during landing and take-off, but also from its Auxiliary Power Unit (APU) when on the ground. FLAPS.25 is able to distinguish 25 different types of emissions, but for this study only the most relevant pollutants were modelled: PM[34], SO_x, VOC, HC, NO_x and CO.

Main engines

Pollutant emissions from the aircraft's main engines were modelled up to an altitude of 3,000ft. This is not an arbitrary limit. Pollutants generally stay below 3,000ft as hardly any mixing with ambient air takes place above this altitude. Also, the impacts of pollutant emissions are largest close to the ground as that is where inhalation occurs. The 3,000ft boundary corresponds to the flight phases that make up the LTO-cycle: approach, landing, taxi-in, taxi-out, take-off and climbout.[35]

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32 The SET methodology is applicable to aircraft with a Maximum Take-Off Mass of at least 5,700 kg. Smaller aircraft types, which mainly consist of passenger flights with less than 10 seats and helicopters represent around 3% of flight departures and 0.03% of Available Seat Kilometers (ASKs) at ACI Europe airports. The fuel consumption for these aircraft types was estimated based on the fuel consumption of the closest resembling aircraft of helicopter for which data was available.

33 The uncertainties regarding the warming impact of non-CO_2 are 8 times larger than those of CO_2 (EASA, 2023).

34 For the aircraft's main engines, a distinction could be made between non-volatile PM (nvPM) and volatile PM (vPM) emissions. For the aircraft's APU the data only allowed for an estimation of nvPM.

35 The 3,000ft boundary is also used for engine certification purposes and for reporting of national emissions under the EU National Emissions Ceiling Directive.

Pollutant emissions – like CO_2 emissions – are calculated by multiplying fuel consumption with the appropriate emission factors. However, the emission factors differ between pollutant species and the various phases of the LTO-cycle. Therefore, FLAPS.25 follows a bottom-up approach whereby the various pollutant emissions are estimated separately for each phase of the LTO-cycle.

Fuel consumption in each LTO-phase is calculated based on the time spent in the phase, the fuel flow per engine in that specific phase and the number of engines that the aircraft is equipped with. Airport-specific taxi-in and taxi-out times are based on Eurocontrol data. Furthermore, it is assumed that reduced engine taxi procedures are applied in 50% of arrivals and 10% of departures based on Pillirone (2020). When reduced engine taxiing is applied, it is assumed that engines need 3 minutes to warm up and cool down. For the other LTO-phases default times are assumed, which are differentiated between aircraft categories: widebody jets, narrowbody jets, regional jets, turboprops, piston aircraft and helicopters.

The fuel flow per engine differs between engine types and LTO-phases and is based on engine certification data. For turbofan, turboprop and piston engines the fuel flows in each LTO-phase are sourced from ICAO's Aircraft Engine Emissions Databank (AEED), the Dutch Emission databank for aviation and airports and from the Swedish Federal Office of Civil Aviation (FOCA) database respectively. Aircraft manufacturers generally offer multiple engine options for their aircraft. This means that aircraft of the same type are equipped with a range of different engine types and variants. Data on actual aircraft/engine combinations was not available for this study. Therefore, the model uses the average fuel flow for the aircraft's engine options, weighted by the number of engines in service on the specific aircraft type. The number of aircraft equipped with a specific engine is sourced from EASA and OpenSky data.

The fuel flow data in the ICAO AEED, the Dutch Emission Databank and the FOCA database is used for engine certification purposes and therefore assumes a standardized (reference) LTO-cycle with fixed thrust settings for each LTO-phase. These thrust settings may not be representative for actual flight operations. Therefore, the fuel flows were adjusted by assuming lower thrust settings using a methodology suggested by ICAO (2020). Multiplying the fuel flow per engine in each LTO-phase with the time spent in each phase and the number of engines gives the total fuel consumption for a specific aircraft/engine combination in each LTO-phase.

Next, pollutant emissions per LTO-phase are calculated by multiplying fuel consumption in each LTO-phase with the appropriate emission factor. As mentioned above, emission factors differ between engine types and LTO-phases. The emission factors are also sourced from the ICAO AEED, the Dutch Emission Databank and the FOCA database. The ICAO AEDB does not contain data on PM emissions for engines that went out of production before 2020. PM emissions for older engines are therefore estimated with the First Order Approximation method (FOA4.0) as suggested by ICAO. The emission factor for SO_x depends on the sulphur content of the fuel. Sulphur contents may differ between batches of aviation fuel depending on the refinery process. According to ICAO (2020), fuel sulphur contents range between 0.005 - 0.068%. For this study the conservative (high) estimate of 0.068% was used.

Finally, summing the pollutant emissions over the various LTO-phases yields the pollutant emissions per LTO-cycle. Multiplication with the number of LTO-cycles at an airport gives the total pollutant emissions at the airport. The number of LTO-cycles was determined by correcting the OAG schedules for cancelled and unscheduled flights.

Auxiliary Power Units

Pollutant emissions from the use of Auxiliary Power Units (APUs) are separately addressed. APUs are common on commercial jet aircraft. Some aircraft types are fitted with two APUs. Smaller aircraft, such as turboprops and pistons often have no APU fitted.

Pollutant emissions from the use of APUs are determined by multiplying the running time of the APU with the emissions per unit of time for the specific APU. Data on actual aircraft/APU combinations was not available for this study. Therefore, the most common combinations were used as suggested by FAA's EDMS and AEDT tools. The FAA was checked against EASA's aircraft certification sheets and corrected whenever necessary. For aircraft types for which no APU information was available, the appropriate APU was determined through desk research.

Actual or average APU running times per airport were not available for this study. Therefore, default APU running times were used as suggested by ICAO (2020). The pollutant emissions per unit of time for each APU were also obtained from FAA's EDMS and AEDT tools. When data on a specific APU was not available, the model uses the rates of an alternative APU for the aircraft type. In case no alternative APU could be identified, the model uses the emission rates for the most common APU for the aircraft category to which the aircraft belongs.

Noise

The noise impacts for each airport were calculated by multiplying the average noise cost per LTO-cycle with the number of LTO's in 2019. The number of LTO-cycles was determined by correcting the OAG schedules for cancelled and unscheduled flights.

Appendix E Synthesis

Figure E.1 Shares of Catalytic, Direct, Indirect and Induced effects on GDP (in billion €)

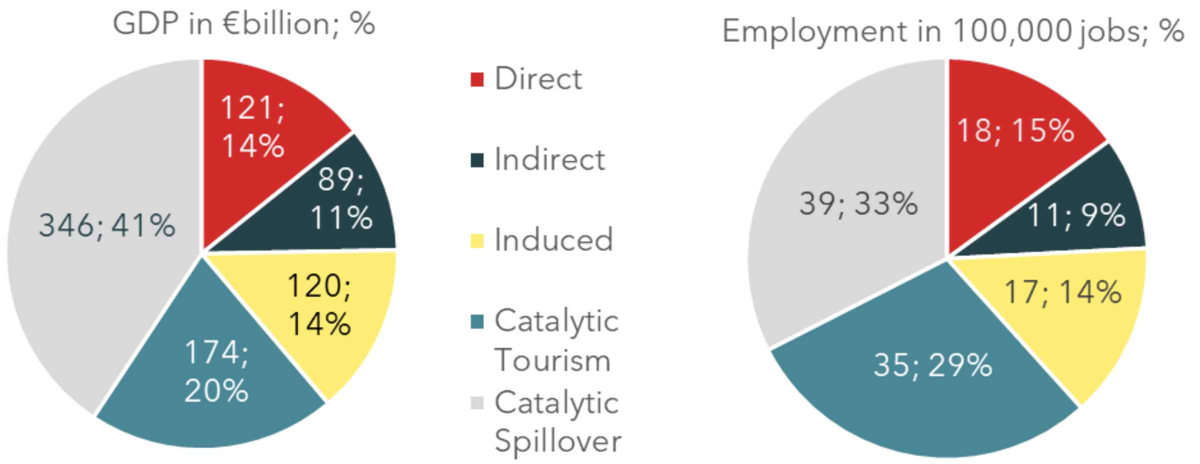

Table E.2 Cross study comparison economic impact

	SEO (2024)	ATAG (2021)	InterVistas (2015)
	GDP in €bn		
Direct GDP	121	210	102
Indirect GDP	89	205	70
Induced GDP	120	152	76
Catalytic – Tourism	174	275	
Catalytic - Spillover	346		
Catalytic - Total	520		427
	Employment		
Direct Jobs	1,843,000	2,700,000	1,696,200
Indirect Jobs	1,126,000	3,000,000	1,353,100
Induced Jobs	1,679,000	2,200,000	1,401,100
Catalytic – Tourism	3,495,000	5,600,000	
Catalytic - Spillover	3,900,000		
Catalytic - Total	7,400,000		7,693,500

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Roetersstraat 29
1018 WB, Amsterdam
The Netherlands

+31 20 399 1255
secretariaat@seo.nl
www.seo.nl/en/

seo • amsterdam economics